ABSTRACT

Title of Thesis: STUDYING THE EFFECTS OF COLORS WITHIN VIRTUAL REALITY (VR) ON PSYCHOLOGICAL AND PHYSICAL BEHAVIOR

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Human-Computer Interaction,

Master of Science, Master of Arts, 2024

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Color theory is an important aspect of today's world, especially when considering user design, technology, and art. The primary objective of this thesis is to examine how the color groups, warm and cool, affect individuals psychologically and physiologically. While combining technological advancements, physiological methods, and psychological analyses, I will try to discover the emotional associations with specific color groups and determine the psychological and physiological impact of color groups on individuals. I hypothesize that warm colors will increase heart rate and skin conductance response, which will directly correlate to emotions of stress and excitement, and cool colors will decrease heart rate and skin conductance, which is associated with the emotions of calmness and positivity.

This study demonstrated that the two-color groups exhibited a notable influence on heart rate. Using the skin conductance response method yielded unanticipated results in comparison to prior research. Prior studies have shown that there is a relationship between heart rate and skin conductance response, and therefore, if one increases, then the other should also increase. This study found that when the heart rate increased, many participants experienced a decrease in skin conductance response, showcasing a contrast in physiological reaction. Furthermore, the study demonstrated a correlation between physiological changes, such as heart rate variations, and corresponding changes in participants' psychological behavior.

STUDYING THE EFFECTS OF COLORS WITHIN VIRTUAL REALITY (VR) ON PSYCHOLOGICAL AND PHYSICAL BEHAVIOR

by

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Preface

Being able to step out of your comfort zone and immerse yourself in other fields is so important. It allows us to learn and grow as individuals. It enables us to share our knowledge with others and move society forward. It makes us curious and enables us to start to ask important questions. This is how I became so immersed in the world of research, because I explored new topics and unfamiliar territory. I sat for hours and read literature that made me wonder why and how. Most importantly, through my background of education, traveling, experiences, and diving deep into unknown topics, I decided that I wanted to make it my sole purpose to focus on research that was meaningful and important and that would help others. This has developed my passion to research for those living with mental health disabilities. I want to one day use the research I conduct to help develop applications for those with anxiety, depression, and post-traumatic stress disorder (PTSD). I hope to one day create an alternative way of treatment for those who cannot afford traditional medication. I intend for my research in this paper to not only guide me in my goals but also to inspire you to dive deeper into the field of research.

Dedication

To

My mother

For always being my number one cheerleader

My Husband

For always supporting me and being my guiding light

To anyone going through a storm

There's always a rainbow on the other side

"If you can make one person believe in your dream, then it's no longer a dream; it's your reality."

-Ciara Fabian

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List of Abbreviations

CMY	Cyan, Magenta, Yellow
CMYK	Cyan, Magenta, Yellow, Black
ECG	Electrocardiogram
GSR	Galvanic Skin Response
Bpm	Beats per minute
HCI	Human-Computer Interaction
INST	Information Studies
LCD	Liquid Crystal Display
µS	Microsiemens
N	Peaks
OLED	Organic light-emitting diode
PANAS	Positive and Negative Affect Schedule
PTSD	Post-traumatic stress disorder
RGB	Red, Green, Blue
SCAD	Savannah College of Art and Design
SCR	Skin Conductance Response
POMS	Profile of Mood States
SSST	The sing-a-song stress test
UMD	University of Maryland
UX	User experience
VR	Virtual Reality Headset

Chapter 1: Introduction

Throughout history, researchers and artists have discussed the idea of color theory, what colors mean, and how they affect us. Some speculate that cool colors can make us calm and that warm colors excite us. There are also some researchers in the mix that do not entirely agree with this idea (Valdez & Mehrabian, 1994). Given that color theory is such an essential aspect of designing interfaces and can also contribute to the world of art therapy and psychology, I developed a study that would discover the effects of colors on emotions using new technology, physiological tests, and psychological measures. My objective was to answer two crucial questions: 1.) What emotions are associated with which specific color group? 2.) How do colors affect us psychologically and physiologically?

This paper aims to answer these vital questions that can potentially help solve other questions in design and also to bridge the gap between art, technology, and psychology. This paper acts not only as a basis for research but also as a foundation to explore Color Theory further. Through this paper and my background in Art, you will be given the knowledge to understand why colors are important by first understanding where they come from and how they are created. You will then learn the principles of how different colors are used in today's world. Once familiar with these topics, this paper will guide you through various methods through previous research and literature reviews that have been conducted in the field. This thesis will also focus

primarily on the background of western color associations and emotional associations.

With this foundational knowledge and the background and guidance from previous work, you will then be transported through my research and methodologies to start to have an understanding of how colors can affect us. Through data analysis and supporting evidence, the hope is to have some of the questions about colors answered. Although there is always room for further research and questions to be answered, the hope is that this paper will act as a guide and premise to help those who are curious about the world of color, technology, and psychology to continue exploring the work within the field using the answers I have found.

Chapter 2: Background of Color

2.1 The Color Wheels

2.1.1 The Types of Color Wheels

In the world of design and art, there are a variety of color wheels that we use. Each color wheel serves a different purpose depending on the use case that the artist and designer applies it to. Based on the *Color Studies* textbook (2014, 3rd edition), the four color wheels we use today are The Pigment Wheel, The Process Wheel, The Munsell Wheel, and The Light Wheel (Feisner & Reed, 2014). It's essential to recognize that each of these color wheels are unique not only in the colors that are showcased but also in how they can be used in design and for other purposes.

The Pigment Wheel comprises what many of us know as the three primary colors: yellow, red, and blue. These colors are the foundation of all of the other colors we see in our day-to-day lives and in the applications, websites, and products we use. These colors are necessary to get the variations of colors and tones we use, such as green and red-orange. Not only are these colors essential to make other colors, known as secondary colors on the pigment wheel, but it is also important to note that because these colors are primary colors (red, blue, and yellow), they “cannot be obtained by mixing”(Feisner & Reed, 2014, p. 12) and can only be sourced directly in their form. It's important to understand that the Pigment Wheel is used to showcase the importance of primaries and how they make the

secondary colors (violet, green, and orange) we use in art and design. Although this color wheel isn't as in-depth as some of the other ones, it's important to know the takeaway from this color wheel is that it is the “basis for working with subtractive color; [and] it imparts information about reactions colors have when they are actually mixed” (Feisner & Reed, 2014, p. 11). Subtractive color means to take away from light to create the final product. To break this down in the eyes of design, this color wheel explains the colors we need to create secondary variation colors in our work. It also helps us analyze the contrast and relationships between primary and secondary colors.

The second color wheel is the Process Wheel. This color wheel is very similar to the pigment wheel as it still gives us some of our primary colors (red, blue, and yellow). The one key difference about this wheel is that this wheel relies heavily on hues, giving us slightly different variations of the primary colors such as “magenta, and cyan - that do, upon mixing, result in purer hues”(Feisner & Reed, 2014, p. 12). The colors represented in this color wheel are important because they are used in our everyday products. For example, you may recognize these colors being used in “color printing and photography”(Feisner & Reed, 2014, p. 12). It's important to recognize that this color wheel is very significant when it comes to design, especially when thinking about products and printmaking, because this wheel showcases what we know as CMYK (cyan, magenta, yellow, and black). Although black is not directly showcased in the color wheel, if you take cyan, magenta, and yellow, “these 3 primary colors are mixed with an equal ratio, the results will be total

black”(Santiwes, 2014, p. 248). These colors are important as they allow us to get better color matches and consistency across our products.

The next color wheel is the most in-depth and detailed color wheel, and it's known as the Munsell Wheel. This wheel showcases primary colors and “five secondaries, and ten tertiaries”(Feisner & Reed, 2014, p. 13). This is essential as it helps designers gauge different hues and contrasts of colors they want to use in their projects. On a deeper note, the Munsell Wheel allows artists and designers to see and pick the colors they want and make deciding factors around “hue, value and chroma” (Hawkes, 1971, p. 16). The first trait of color, Hue, allows us to choose the gradient we want for a color. This is also “for setting the overarching theme for your painting” (Scott, 2023). You would choose a hue using the Munsell Wheel by looking at the two primary colors you want to mix and then deciding which primary color you would like to have a higher percentage of concentration in the color mix. For example, if an artist wanted a yellow-green-yellow for their project, they would mix a higher ratio of yellow with green to accomplish that hue.

The next color trait from the Munsell wheel is Value. This trait is used when a designer or artist wants to choose a color based on its darkness or lightness. Value is important in design because it allows the designer to carefully select the color contrast that they want to use in their final product. This can be imperative not only for aesthetic purposes but also to ensure that the final design is accessible to all by ensuring “the visual presentation of text

and images of text has a contrast [and value] ratio of at least 7:1”(Eggert et al., 2023) on products, applications, and websites.

The last important aspect creatives can find using the Munsell Wheel is the Chroma in which they would like to use. This trait “is a measure of a hue or color’s purity”(Feisner & Reed, 2014, p. 88). This is important as this trait is “used in association with intensity [...] which is synonymous with saturation” (Feisner & Reed, 2014, p. 88). It is also important to take into consideration when implementing a design in technological applications as colors can be shown in a multitude of ways depending on the screen and system (i.e., Liquid Crystal Display (LCD), Organic light-emitting diode (OLED)).

The last color wheel that is important to touch upon when discussing color in design is the Light Wheel. This wheel is important as designers can apply the colors from this wheel in more technical applications and in digital sectors (Feisner & Reed, 2014). For example, this wheel's colors can be used in many ways, such as in “theatrical lighting and projection and is now the basis for video, computer graphics, and electronic media” (Feisner & Reed, 2014, p. 14).

This color wheel is used in technological sectors because of the colors found: green, cyan, blue, magenta, red, and yellow. The reason these colors are important in technology is because of the capacity of the screen displays and lighting capabilities. For example, an OLED screen uses Red, Green, and Blue (RGB), and depending on the type of colored light bulb being used in lighting, cyan, magenta, and yellow (CMY) can be used, or RGB can be used.

The light wheel is so important as it not only helps us understand the way colors in display lights work, but also helps us understand that “RGB (red, green, and blue) [is the] additive color model and the CMYK (cyan, magenta, yellow, and black) [is the] subtractive color model”(Rosi et al., 2018, p. 272). Additive colors is when you mix colors together in order to create other colors until eventually creating white. Subtractive colors are created by taking away from white to get the desired color outcome.

2.1.2 The Importance of The Color Wheels

Color wheels are an important aspect of Art and Design. They are the basis of understanding colors and the relationships between each one. Color wheels are also used as a “tool to create harmonious color schemes” (Stokley, 2018, p. 4). Color wheels allow us to make informed decisions on what colors to use based on traits such as shade, color contrast, and much more. In turn, designers can use this information and turn it into the products we use every day.

These color wheels not only allow us to understand the basic principle of colors and the importance of how to use them in contrast or complement one another, but they also help us understand how to create other colors using primary colors. Color wheels have an overall history of helping us create tones and moods throughout artwork and product design. They also allow us to choose the colors in regards to making our work feel dark or light. Looking at Andy Warhol's work of Marilyn Monroe (Warhol, 1967) this is a

prime example of using the color wheel to the artist's benefit and to create work that led the pop art era movement. In his work, we can see how he carefully chooses colors based on whether they are complementary to one another. In this piece of work, there are two sets of complementary colors: red and green with yellow-orange and blue-violet. These complementary colors can also be seen on the pigment color wheel. This work showcases how impactful color wheels are in art and design and how they are used to make up the art we all know and love.

Overall for us to understand design, whether in art or technology, we must understand the basics of color wheels. It's important to have an understanding of how colors are created, especially when it comes to secondary and tertiary colors. Without a basic understanding of colors, especially ones that complement each other to make a unified design, it can be difficult to understand design thinking and the creation of the process of art and design in technology. Color wheels are not only important for our understanding but also essential for us to use so that we can make long-lasting and impactful creations that we can implement in the world through our technological applications and traditional art.

2.2 Color Variations

2.2.1 Color Groups

Through understanding all the color wheels and their unique representations and use cases, it is also important to note their similarities. Throughout all four color wheels, there is a common theme in which all the colors represented can be separated into two color groups. These color groups are known as Warm Colors and Cool Colors. These color groups are important as they allow designers to make informed decisions based on how they want to “set the brand tone and influence its image, draw users’ attention, affect their emotions, and increase usability” (Gordon, 2024). The differentiation and understanding of cool and warm colors is so important as it influences the craft of design.

Looking at the makeup of warm colors this includes yellow, red, orange, and variations of these colors. Depending on the color wheel being used and whether or not it includes secondary and tertiary colors; the color green-yellow can also be counted as a warm color. In design, knowing what colors are part of the warm color group is important because many times viewers will associate warm colors with certain subject matter. “Warm colors like red and orange can create excitement and draw more attention from users. Thus, using these colors may help stir your users' emotions or behavior” (Rush, 2023). Warm colors can be seen in various use cases such as horror games and films, fast food brands, and even in architectural builds

such as playgrounds. Not only can warm colors affect our attention but it can also affect the way we perceive things in applications and artwork. In chromostereopsis artwork, which is “ a type of visual perception where a specific color is perceived closer to or farther from the observer than other colors in the plane pattern” (Hayashi et al., 2012, p. 617), warm colors such as red appear closer than cool colors. This showcases the importance and overall effect of how a color can change the way something, such as an application, is viewed simply because of the group it belongs to.

Cool colors have just as much uniqueness and impact as warm colors in the art and design world. Cool colors include blue, green, and violet, and depending on the color palette, variations of red-violet. Cool colors are important as they allow us to implement certain themes and effects into designs and artwork. One way cool colors are used in traditional artwork and design is as a means to create depth. This can be seen in various ways, such as shadows, sky backgrounds, backdrops on applications, and much more. The FedEx logo (Crawford, 2023) is a great example of taking advantage of the depth that cool colors can create, especially when contrasting them against warm colors. In the logo, it is apparent that the violet color creates a deep depth of perception to allow the warm colors to be brought forward to the user's eyes. This is an important aspect in design as it allows for key center points to be created so that main subject matter can be highlighted simply by using the correct color group. Not only is this seen in digital media such as logos, but this is also seen in traditional artwork. Looking at the art

piece Waterlillie by Cheryl Gilarsky (Gilarsky & Jeffs, 2024) the artist carefully used the cool colors of blues and green to create a center focus of the lilies. The reason this method works is because “cool colors are known as “receding colors”(Harleman, 2007) that appear to be farther away” (Naz et al., 2017, p.4). This methodology is important when deciding what colors to use in a design as it will make a difference in how the final layout and focal point will look like.

Knowing the difference between warm and cool colors is an essential foundation to design and art. Knowing which colors to use from each color group allows for designers to decide what type of effect they want to create. It allows artists to create focal points and accurate depictions of subject matter. Not only are color groups important to create perspectives in design and art but are also important in order to set the tone and mood. This is especially true when looking at applications and particularly on hardware such as the Virtual Reality Headset, Oculus(meta) Quest. Since the Oculus is an immersive experience, choosing the correct color group is an important factor when wanting to set the tone and the mood of the environment. Later we will go more in depth on how colors and color groups affects one's emotions and perception of mood based on previous studies and the emotion color wheel.

2.2.2 RGB vs. CMYK

Earlier we spoke about RGB and CMYK and the color make up of both. RGB and CMYK are important concepts to be informed on as they determine the color palettes we can use depending on the technology we are building for. The difference that RGB and CMYK can make is substantial as it can affect the way our work turns out on the screens and print. The following will not only showcase the differences between both but also show how both are applied in today's world.

It's important to remember that RGB comprises three colors: red, green, and blue. RGB is a model based on the idea of wavelengths, and that these three colors are considered additive because together, they can create several other colors (Zelazko, 2024). These three colors are important as scientists have found that the average human eye color vision works by means of three receptors within the eye that measure different wavelengths (Grzybowski & Kupidura-Majewski, 2019). This is also known as the trichromatic color theory which states that “that there are three different cone systems in the eye that perceive three types of color: blue, green, and red” (Nickerson, 2023).

The trichromatic theory has also been applied to digital device screens such as computers, phones, and other devices with displays. The reason for this is because in these devices the micro lights, also sometimes known as diodes (Behrman & Kymissis, 2022), in pixels are made up of the three colors RGB. In order to see other colors other than red blue and green, the micro

lights will increase and decrease in brightness to create the applicable color; for example if the red, blue, and green lights are on then the pixel will appear white (Works, 2002) but if only the red and blue light are on then magenta will be created. The colors will change based on which color lights are on and the brightness of the lights. Recognizing RGB and its use case is important, especially when looking at designing for digital screens. Later on, we will look at how RGB contributed to testing and how RGB affected the viewing of the testing simulations within the Oculus Quest Headset in correlation to the colors shown to each participant.

It's important to also recognize CMYK and how it differentiates from RGB and why it's not primarily used on digital devices. CMYK is made up of the colors cyan, magenta, yellow, and the color that is created by mixing all three of the colors together; black. Unlike RGB, this color model is subtractive because the colors used in this model take away from light in order to create more colors.

CMYK is used in printing and how when using this model, printing starts with white. In order to get the finished product, the image subtracts little by little from white by adding each color in order to get the final image (Dinfos, 2021). Since CMYK is based around the concept of using color to take away from light, it is not typically used in digital displays but instead in printings like the one above. The reason CMYK is used for printing is because it allows for a more exact color to be produced (Azad et al., 2017). When wanting to print it is important to design for the CMYK color model as if you

design on a screen with the RGB model once you print you will not receive the same results as you designed on screen. Color in artwork can vary drastically in visual outcome depending on if RGB or CMYK was used as the basis (Ulens, 2001), which is why it's important to design for the correct model especially when wanting to convert a product from digital screens to physical print.

Understanding RGB and CMYK is essential when looking back at the variety of color wheels you can elect to use and pick colors from. Knowing what colors are used for various end products is essential for a successful final outcome and design. RGB and CMYK is especially important when doing testing on devices as it is imperative to know how designs will be showcased and understand the final viewing output.

2.3 Color Theory

2.3.1 The Meaning of Color Theory

Color theory is an essential part of art and design as its the foundation of understanding colors, the color models and wheels, and how colors are applied in principle for technology and physical products. “Color theory is the study of how colors work together [...] It's like a toolbox for artists, designers, and creators to help them choose the right colors for their projects” (Interaction Design Foundation, 2024). Not only is color theory about how colors work together and how primary, secondary, and tertiary colors are

combined and created, but color theory is also about perceptions and how colors affect us emotionally (Interaction Design Foundation, 2024).

2.3.2 Importance of Color Theory

Color theory is so crucial as it allows designers and artists to construct their work on the principle of color usage and how colors affect perception among users. Color theory allows us to have a better understanding on how to create a cohesive design, and therefore, is important to create final works that have meaningful impacts in the ways we intend. Not only is color theory important to have an understanding of in order to create good design, but it's also important as it allows us to begin to notice the impacts of certain colors in designs. Color theory takes into account user's emotions, and this can be seen in how companies are using specific colors in order to create the impact they want. An example of this is in fast food restaurants where many companies have elected to use the color red as studies have found that red can stimulate emotions in users such as excitement, energy, and even appetite (Braam, 2024). This is just one of the many examples of how color theory can affect emotions and perceptions. Later we will review how color theory affects users and the importance that color theory has in testing within Virtual Reality (VR).

2.4 Why Knowing The Background of Color is Important

2.4.1 Chapter Conclusion

The purpose of this chapter was to give insight into the world of colors and to explain how colors are used and even created by showcasing the different color wheels, effects, color groups, and color models. Having this foundational knowledge allows for a better grasp of how important colors are in today's society and in everything we use on a daily basis. With this knowledge, we can now discuss how colors affect us especially when it comes to the use case of color in technology. Knowing how to apply this foundational information is important as it can have a real-life impact on how we use color in our designs and products.

Chapter 3: Colors, Emotions, Related Work, and Psychology

3.1 Emotions and Color Correlation

3.1.1 Beliefs and Plutchicks Wheel

Colors are known to be associated with certain emotions, tones, and moods. Looking deeper into how colors affect one's emotions, throughout history, researchers and artists have discussed the idea of color theory, what colors mean, and how they affect us psychologically and emotionally. Many, such as Mitsuhiko Hanada, believe that cool colors can make us calm and warm colors can excite us. Specifically, he believed that “red is associated with anger and excitement [and] green with peacefulness and calmness” (Hanada, 2017). Although many would agree with Hanada (2017), there are a few theorists who do not entirely agree with this idea. Researchers such as Niels Nijdam believe “the plus part or positive part are colored yellow, red-yellow (orange) and yellow-red (vermeil) […] The negative consists of the colors blue, blue-red, and red-blue; these colors stand for restless, yielding, and yearning”(Nijdam, 2009, p. 2).

One model that can be used in art and user experience (UX) design when trying to determine what color is associated with what specific emotion is *Plutchick’s Wheel of Emotions* (Interaction Design Foundation, 2024). To start it is important to note that this wheel was not originally created with the

intent to attach colors to emotions. Instead, Robert Plutchik created this wheel model in order to showcase how emotions relate to one another and how emotions can evolve. This wheel model is also used to showcase emotions and show how they can be mixed or intensified to create other emotions (Interaction Design Foundation, 2024).

Even though Plutchik's wheel of emotion was not originally meant to act as a direct correlation to colors it has since been used in the creative industry. This wheel was meant to reflect as a "color palette"(Interaction Design Foundation, 2024) of emotions, and therefore it is sometimes used in art when it comes to assigning emotions to colors from the Pigment or Process color wheels. Unfortunately, there are many limitations when trying to assign colors from the Munsell wheel as emotions aren't assigned to many variations of colors. As a basis, the Plutchik model is a great foundation for designers to carefully craft their prototypes and designs based on color and emotion. However, further research needs to be done to truly know the impact of color usage as there is not enough scientific backing in using the Plutchik's wheel. Its important to keep in mind that this model was not created as a means for color comparison but to showcase how emotions interact with one another in psychology (Foundation, 2024).

3.1.2 Research Using the Munsell Wheel

Although the Plutchik wheel can help designers have a basic understanding of emotions and colors, the true understanding of colors and

their associations with emotions comes from studies and research that have been previously conducted. Valdez and Mehrabian *(1994)* made an interesting discovery using the Munsell color model and studying the effect of colors on users' emotions by measuring the change with the Pleasure-Arousal-Dominance model. Valdez and Mehrabian *(1994)* found that colors such as purples and blues are seen as more pleasant when it comes to emotions, unlike warmer colors such as yellow, which are seen as negative and even have a correlation to increased energetic stress levels (Valdez & Mehrabian, 1994). Although this study does not break down specific emotions into specific colors, this information is still very useful in design. Knowing which color groups to use to stimulate even general emotion and have an effect on pleasure and arousal is a step in the right direction.

One way the information from this study could be used is in sleep aid applications. Knowing that purples and blues (also known as cool colors) have a more pleasant effect when it comes to emotions could sway a designer to implement those colors. This is just one of the many ways this information can be used in designs. Later in this paper, we will look at other studies and findings on the impact of colors on emotions and how they can be further tested for accuracy and credibility.

3.2 Colors and Psychology

3.2.1 Emotions in Psychology

When taking a look at how colors affect emotions, it's important to first have an understanding of what emotions are from a psychological standpoint. In psychology, emotions are reactions that we experience due to a specific event, person, or object. These reactions create behavioral changes and psychological changes, which we know as emotions (American Psychological Association., 2024). It's important to know that emotions are unique to each person and, therefore are subjective (UWA, 2019). This means how one person may react to a certain situation isn't necessarily how another person would react. This is important to recognize as understanding and breaking down emotions can be very complex.

In psychology, it is imperative to recognize that there is a difference between emotions and feelings, although they do coincide with one another. Many times, feelings are used synonymously with emotion when, in actuality, emotions are known to play a role as “unconscious thought” (Pettinelli, 2007, p. 3), unlike feelings, which are considered to be more of a sensation that we can easily recognize, such as feeling touch (Pettinelli, 2007). In this paper, we will be focusing on emotion and the importance colors play on a user's emotions especially when it comes to user interfaces.

3.2.2 Psychology Scales (PANAS)

One way emotion can be measured is through a scale called the Positive and Negative Affect Schedule (PANAS) (Watson & Clark, 1994) (See Table 1.). This scale helps gauge emotions in a quantifiable way. The PANAS scale allows for positive and negative emotions to be measured on a scale from 1-5. The scale consists of 20 different emotions. Specifically, there are ten positive affect emotions and ten negative affect emotions within the scale. The following are the emotions within the scale: interested, distressed, excited, upset, strong, guilty, scared, hostile, enthusiastic, proud, irritable, alert, ashamed, inspired, nervous, determined, attentive, jittery, active, and afraid. Each emotion is measured by participants gauging each emotion on a

Table 1.

Positive and Negative Affect Schedule (PANAS)

		"1" VERY SLIGHTLY OR NOT AT ALL	"2" A LITTLE	"3" MODERATELY	"4" QUITE A BIT	"5" EXTREMELY
1	INTERESTED	□	□	□	□	□
2	DISTRESSED	□	□	□	□	□
3	EXCITED	□	□	□	□	□
4	UPSET	□	□	□	□	□
5	STRONG	□	□	□	□	□
6	GUILTY	□	□	□	□	□
7	SCARED	□	□	□	□	□
8	HOSTILE	□	□	□	□	□
9	ENTHUSIASTIC	□	□	□	□	□
10	PROUD	□	□	□	□	□
11	IRRITABLE	□	□	□	□	□
12	ALERT	□	□	□	□	□
13	ASHAMED	□	□	□	□	□
14	INSPIRED	□	□	□	□	□
15	NERVOUS	□	□	□	□	□
16	DETERMINED	□	□	□	□	□
17	ATTENTIVE	□	□	□	□	□
18	JITTERY	□	□	□	□	□
19	ACTIVE	□	□	□	□	□
20	AFRAID	□	□	□	□	□

Note. The PANAS in which was used to conduct the study and quantify participants emotions. *"From* Watson, D., & Clark, L. A.,1994. Copyright © 1994, David Watson and Lee Anna Clark.

scale from 1 to 5. The number represents the following: 1 = very slightly or not at all, 2 = a little, 3 = moderately, 4 = quite a bit, and 5 = extremely. By using the scale of 1-5, users can measure what their emotions are at that current moment and narrow it down by how much or how little that emotion is affecting them.

The PANAS scale is useful for multiple reasons when it comes to measuring emotions. Studies conducted by Jolly, Dyck, and Kramer (1994) showed the success that the PANAS scale can have on being able to differentiate between depression and anxiety. They conducted an evaluation of self-reporting using the PANAS scale with 159 psychiatric patients. They found that the negative affect emotions with higher ratings on the scale were very prevalent with anxiety (Crawford & Henry, 2004). This is an important finding as this means Anxiety in this study can be directly correlated with emotions such as nervousness and irritation on the PANAS scale.

Because the PANAS scale is a measurement of emotion, it has also been used to study the direct effects of colors on users. Research conducted by Liew, Tan, Gan, and Pang *(2022)* tested how colors affected emotion among 204 participants. The way this study was conducted was by showing different color themes such as: warm colors, cool colors, and grayscale colors. Each participant was shown multimedia that consisted of one of the color themes which was selected randomly through the online platform. Each participant viewed there selected multimedia color group in phases. Once the participant completed the interaction with the multimedia the researchers

used PANAS along with other methods in order to measure the participants self assessed emotion. Through this study, they were able to find that participants who were exposed to the cool color group resonated more with emotions such as ‘proud’ and ‘interested’, unlike those who saw warm colors who resonated more with emotions such as ‘alert’ and ‘active’ (Liew et al., 2022). This study supports how the method of using PANAS can be used to measure how emotions relate to colors, especially different color groups. This study is important as it supports the basis of the research that has been conducted for this paper.

3.2.3 Colors in Psychology

Colors can be directly correlated with methods and emotions found in the field of psychology especially when looking at the use case of color in art therapy. Many therapists, especially ones who work with art mediums within the therapy sector, have the question of what color is associated with what emotion? There are several studies that have been conducted to try and find the answer to this question. One study was conducted at Vermont College where they took 69 students and observed the emotional effects of certain colors and color groups. These psychologists found by using *The Profile of Mood States* (POMS), they were able to observe participant's reactions toward specific colors. In the study, they found that cool colors, such as blue violet, created fatigue among participants. The research also found that colors, such as red, are more stimulating and increase activity levels and

alertness (Withrow, 2004). These findings are substantial in psychology as they help showcase the basis of how colors can affect us emotionally.

Colors are important in Psychology because there are many studies that show that they can affect our moods and perceptions in different ways. Whether that's through an application on your phone or even the color of the walls in your house, colors can have a significant impact on our psyche (Mental Health America, 2024). This is why testing how colors affect us psychologically is so important, as having this knowledge can have a significant impact on our designs. Understanding the importance colors have in our designs based on the psychological effect will help to create more impactful outcomes within our applications and also allow us to eventually create applications that are more ethical by ensuring that we are using color themes that are not triggering and harmful to users and instead are using colors that users can enjoy and feel at ease with.

3.3 Testing Colors and Emotions

3.3.1 Previous Testing of Colors and Emotions

As previously stated, there have been many studies conducted to test how colors affect one's emotions. Each study uses a unique method in order to showcase how colors can have a significant impact on our psychological behavior. The following section will illustrate a few examples of testing

between colors and emotions in order to showcase the many ways in which the relationship between the two have been studied and represented.

One interesting study that was conducted to test emotions and color was conducted by Hanada (2017). He looked at how colors were associated with emotions by conducting a study with 40 participants and asking them to associate an emotion they felt appropriate to each color that was shown to them. Through testing, Hanada (2017) was then able to take this data and find the overall connection between emotions and colors. Hanada (2017) found that even on a small scale, participants would respond in a similar manner in correlation to the colors being presented to them. Although it was difficult to find a common association with specific colors, such as reds and blues, it was found that there were common associations among temperatures of colors, such as warm and cool. Results among participants showed that emotions such as anger and excitement were associated with those colors associated with warm temperatures. Emotions such as calmness were mostly associated with cool colors (Hanada, 2017). These findings are imperative as they showcase how, although it can be difficult to pinpoint emotions to specific colors, temperature groups of colors such as, warm vs. cool, have a much greater effect.

Another study showcased the relationship between emotions and colors. This study conducted in 2020 by Jonauskaite, Parraga, Quiblier, and Mohr, tested color patches and word associations with 132 participants. The researchers presented 12 colors using two methods: 1.) Participants were

shown the colors in black writing, so instead of showcasing the physical color, they were just showcased the color in word format. 2.)The second method showed the actual color patches to each participant. For both methods, the participants were asked to fill out the Geneva Emotion Wheel (GEW) (Jonauskaite et al., 2020) for each color that was presented. This wheel allowed participants to not only choose the appropriate emotion they felt best associated with the color they were being shown, but it also allowed them to showcase the intensity of the emotion by either filling out a small circle for very little or a large circle for very intense (Jonauskaite et al., 2020).

This study was important as the findings not only showcased the overall emotion associated with each color but also quantified the intensity of the emotion for each color. Through this study, researchers found that among both written colors and physical patch colors, 51%-73% of participants associated negative emotions, such as hate and anger, with the color red, and 38% of participants associated relief with the color blue (Jonauskaite et al., 2020). This finding shows two important conclusions. The first is that colors such as red are a lot more effective in creating intense emotion among participants. The second important conclusion is that this study can be tied to and compared to the study done by Hanada (2017). In both studies, warm colors, such as red, had more of a negative effect on participants than cool colors.

Recognizing the findings in these studies is imperative as these studies are the basis of my hypothesis that I will discuss in Chapter 4. These

studies are also important because understanding how colors affect participants psychologically also allows us to begin to search further on how emotions correlate with how colors affect us physiologically based on our emotions.

3.4 Heart Rate Testing

3.4.1 Testing of Colors and Heart Rate

Looking at colors and how they affect us emotionally, it's also important to look at how colors can affect us physiologically due to their impact on our emotions. In a study conducted by AL-Ayash, Kane, Smith, and Green-Armytage (2015) at Curtin University, these researchers created a test to look at how six colors: vivid red, vivid yellow, vivid blue, pale yellow, pale red, and blue, affected 24 participants' emotions and heart rate. In the study, they found that participants were notably affected by both hues of red and yellow. The researchers found that even with the difference in hue, reds and yellows still had a more significant impact on heart rate than the contrasting color of blue. Even though the heart rates were higher in warmer colors, they found that participants rated pale yellow and pale blue with more positive emotions. These pale colors were also rated with more positive emotions, such as being calming. Overall, vivid blue and pale blue were found to have the lowest heart rate, and 62%-70% of participants found that these two colors were more peaceful and had a more positive effect on their overall concentration and emotional well-being (AL-Ayash et al., 2015). This study

showcased how colors can affect not only psychological behavior but also our physiological behavior. Although this study had a small participant pool, the results still showed the significance that colors can have on users. This data is important as it allows us to create further studies that will support the theory that colors play a role in psychological and physiological science.

3.4.2 Testing Heart Rate and Emotions

There are many methodologies to test heart rate in relation to emotional stimulation. Although it can be difficult to pinpoint exact emotions with heart rate, there have been studies that have conducted tests on heart rate with overall negative and positive emotional stimulation. A study conducted by Johnston and Anastasiades (1990) observed how heart rates changed due to emotional stimulation. The study monitored 32 participants with no known health or cardiovascular problems. During the testing, electrocardiogram (ECG) changes were monitored for each participant. During testing, participants were asked to fill out a mood survey which had questions that measured arousal, stress, and time pressure. Through this study, Johnston observed that in some participants, heart rate had a direct correlation with stress. It was also concluded that negative emotions such as stress can be associated more with increased heart rate. Lastly, Johnston and colleagues found that participants who had shown a relationship between their emotions and their heart rates were also more likely to experience negative emotions such as anger and anxiety (Johnston & Anastasiades,

1990). This research is important as it showcased the correlation between heart rates and emotion and how negative emotions could be correlated to an increase in physiological arousal, such as heart rate.

3.5 Skin Conductance

3.5.1 Skin Conductance Method

Skin conductance is a unique method to measure the amount of arousal and emotional stimulation that a person is experiencing. This is monitored through a skin response monitor, sometimes known as a Galvanic Skin Response (GSR). These systems measure the amount of electrical conductivity created by measuring the amount of micro sweat created through sweat glands by using electrodes (disposable or non-disposables) and placing them on the body (Albert & Tullis, 2023), especially in places that have a substantial amount of eccrine sweat glands (Biaggioni et al., 2012). The output for skin response data is known as Skin Conductance Response (SCR), which is expressed in microsiemens (μS) (Braithwaite et al., 2015). The average baseline μS for humans is anywhere from 2μS to 20μS. The GSR testing method is unique because, unlike some responses that can be controlled, such as the way we describe something, the majority of people cannot control their SCR to a GSR test since it measures micro sweat produced. GSR can be used as a measurement of stress and arousal and, in turn can be used as a tool to measure emotional response.

3.5.2 Skin Conductance and Emotion

Because skin response is based on the amount of micro sweat we produce and the electrical conductivity that is created, it has been used as a tool in research studies to test how emotions play a role in physiological responses. It has also been used as a tool to test how technology affects us emotionally and physiologically. A study that looked at how Virtual Reality (VR) environments affect users by looking at the changes in skin conductance among participants was conducted by Polo et al. (2023). The study had 37 participants view various scenes that represented one of the following four emotions: happiness, fear, relaxation, and sadness. The VR scenes were created using another pool of participants who gave feedback on each experience until a consensus could be made on what emotion was assigned to each VR scene. Each of the 37 participants viewed each scene for 5 minutes. During the testing of the participants in the headset, their skin conductance was monitored with a Procomp Infinity system. With the data collected, they were able to observe the number of peaks (N) that occurred in the participant's SCR during each scene (Polo et al., 2023).

This study was able to showcase that the emotion fear created the most peaks in the SCR. This can be correlated back to the idea of arousal and showcases how some negative emotions can be correlated with higher skin conductance. This study also helps support the idea that positive emotions are correlated with less arousal and, therefore lower SCR. The only outlier was the emotion sadness which had a similar number of SCR peaks as the emotion happiness. Nonetheless, participants still had more arousal with the negative

emotion of sadness compared to the positive emotion of relaxation (Polo et al., 2023), supporting the theory that negative emotions typically will have a higher SCR level on average than those of positive emotions. This study showcases the importance of the use case of using SCR in studies that measure positive and negative emotions. Measuring and observing SCR is a great tool to use alongside other methods when testing the effects of emotions, colors, and technology, as it is objective and very difficult to manipulate.

3.5.3 Skin Conductance and Heart Rate Correlation

SCR measuring is used in various fields and scenarios, including, but not limited to, medical biofeedback and criminology polygraph tests. Due to the nature of GSR testing and its versatility to be used in different domains, it is also typically found as a supporting physiological data collection point alongside other tools and methods in research. It's important to also recognize that much of the physiological data that is collected is also influenced by other types of data, such as heart rate and skin conductance, and the influence between the two. A study conducted in the Netherlands by Anne-Marie Brouwer and Maarten Hogervorst (2014) looked at how induced stress affected physiological data such as heart rate and skin conductance. In this study, 25 participants were put through a stress manipulation. Prior to singing the song, the participants were asked to read phrases that were presented to them. Once reading the 9 phrases, the 10th message presented to them stated a task to sing the phrase instead of reading it in order to simulate induced stress (Brouwer & Hogervorst, 2014).

By conducting this study, they were able to measure the amount of stress that was induced from reading to singing. Looking at the data they collected, they were able to showcase how, before the moment of stress, both in the skin conductance and heart rate, there was a steady baseline overall for participants (Brouwer & Hogervorst, 2014). It is also apparent that although at the start of testing, changes in the SCR were not as apparent as the heart rate, there was still elevation in both the skin conductance and heart rate before sentence 1. Once the participants were prompted to sing the phrase they were introduced to, you can see the sudden increase in both heart rate and skin conductance (Brouwer & Hogervorst, 2014). This study showcases the importance of using multiple physiological measurements for induced stress and stimulation. It also supports the idea that when a participant's heart rate increases due to sudden stimulation, then the SCR level should also increase in concurrence with the heart rate elevation.

3.6 Connections & Conclusions

3.6.1 The Connection Between SCR, Heart Rate, and PANAS

Looking at the previous testing and research conducted, there is a common connection that can be made. Each of these tools are a supportive measurement of emotions and stimulation, especially when conducting research on how something affects a participant. It's clear from supporting evidence that was previously discussed, that Heart Rate and Skin Conductance can both be used to recognize patterns of stress and high

emotions in users. Since Heart Rate and Skin Conductance can be representative of stress and arousal levels, it can also be used alongside a psychology scale such as the PANAS scale. The PANAS scale includes emotions of different valence with different arousal associations. Although not all 20 emotions of the PANAS scale are on the arousal-valence emotional plane (Ramirez et al., 2018), looking at the plane, in general, allows us to predict which emotions will cause arousal. Knowing this, we can compare measurements of heart rate and skin conductance alongside the PANAS scale and gather data on not only what emotions people are having in a situation but also how those emotions physiologically affect them. Having these methods in research are important, especially as together they give you more data outputs and also support the validity of what is being studied.

Chapter 4: Research Influence and Hypothesis

4.1 Research Influence

4.1.1 Previous Testing of Colors With Physiological Methods

A research study conducted at Johannes Gutenberg-Universität Mainz by Wilms and Oberfeld (2017) looked at how different hues, brightness, and saturations of the colors Gray, Red, Blue, and Green affected 65 participants' emotions. They used three methods of measure to evaluate emotion within

this study. They used heart rate, skin conductance, and the “self-assessment manikin (SAM)” (Wilms & Oberfeld, 2017, p. 900) that allowed the participants to rate their emotions based on arousal and valance (Wilms & Oberfeld, 2017). During testing, each participant was exposed to 9 variations of gray, red, blue, and green. Each variation varied in different hues, saturation, and brightness, which were scaled low, medium, and high. The participant was shown the colors and then rated their emotional state while their heart rate and skin conductance were being monitored (Wilms & Oberfeld, 2017).

Through this research, it was found that color stimuli have an apparent effect on one's physiological and psychological response. One result within the study showed how arousal was significantly affected when the brightness of the color was higher. Observing the data, also showcased how the warm color red had a greater effect on arousal than the opposing cool colors of blue and green. The study also found an increase in brightness caused a stronger physiological response among participants. The skin conductance among participants increased with brightness and colors. The heart rate of participants also increased when the brightness of chromatic colors was higher (Wilms & Oberfeld, 2017).

This research showcases the importance of colors and how stronger colors, whether that's due to their specific color or brightness, have an effect on physiological and psychological outcomes. This study can be researched further using different methods, such as more specific emotions and, instead

of different traits of colors, looking at different color groups and their effect on physical and emotional data results.

4.2 Hypothesis

4.2.1 Background and Prediction

The basis of my hypothesis and study has been developed using previous research that found that "Heart rates were significantly affected by hue; [and that] they increased in the red and yellow conditions”(AL-Ayash et al., 2015, p. 196) and "blue increased relaxation and calmness feelings of participants compared to the other colors” (AL-Ayash et al., 2015, p. 196). I will be conducting a study that will look at how particular colors shown in Virtual Reality (VR) affect a person’s emotions and thinking by measuring heart rate, beats per minute (bpm), skin conductance response (SCR), and using the psychology scale of Positive and Negative Affect Schedule (PANAS). I hypothesize that warm colors will increase heart rate and skin conductance, which will directly correlate to emotions of stress and excitement, and cool colors will decrease heart rate and skin conductance, associating with the emotions of calmness and positivity.

4.2.2 Importance of Research

Conducting this study could help create new ways of dealing with those with anxiety and other mental health issues in the psychology world. “Apps for anxiety [are] increasing, [and] attrition rates among mobile apps are high. These apps must be engaging and relevant to end users to be effective;

thus, engagement features and the ability to tailor delivery to the needs of individual users are key" (Balaskas et al., 2021). Knowing the effects of colors on the emotional behavior of a person could be used to tailor applications and devices that aid in the individual needs of users with anxiety and could help alleviate symptoms of anxiety and potentially other mental health issues as an alternative or joint therapy with traditional medicine.

Chapter 5: Technology, Overview, and Procedures

5.1 VR Technology Used

5.1.1 VR Headset Information

This study was conducted using an Oculus Quest 2, also known as Meta Quest 2 (Quest, 2024). This is a Virtual Reality Headset (VR) created by Reality Labs under the company Meta (Originally known as Facebook). This device is a fully immersive headset built in with audio speakers and a microphone. This device is also adjustable and, therefore, can fit most if not all head sizes. In order to use this device, it is required to have a computer that can run the device software or a smartphone such as an Iphone or Android. This device comes with 2 controllers that control the interactions within the headset. The headset has an LCD screen that runs on the color model of RGB which has a viewing resolution of 1832 x 1920 (Quest, 2024).

5.1.2 Reasoning for Oculus Quest 2

The reason the Oculus Quest was chosen is due to its flexibility compared to other VR headsets. The Oculus Quest enables developers to create their own apps and deploy it to their personal headset. This feature was imperative in order to conduct the study as I needed to create my own Unity application and needed to run the application on the headset during testing sessions. Another reason I selected the headset was because it allowed for live streaming during testing. This was important as I needed to ensure that the video application that was being shown was working properly for the duration of testing. I also was able to remote start it by streaming it; meaning the simulation of colors were only started once the participant was ready and everything was set up properly. Lastly, the reason I elected to use this specific headset is because it was adjustable and allowed for those with glasses to still be able to use it. This was important as some participants needed the headset adjusted and wore glasses so having a VR headset that was easy to fit to everyone made the study testing more efficient.

5.1.3 The Importance of Using a VR headset

The reason that a VR headset was used in this study was to mitigate the amount of distraction factors. A VR headset is a fully immersive experience meaning that once a user is in the headset they can only see the display within the headset. Since this research was focused on colors and what was being viewed at the time of testing, it was important to isolate the

factors which could be seen. Being able to have total control of what the participant could view allowed me to be able to validate the results that were being seen in connection to the colors being shown to the participant.

5.2 Skin Conductance Technology

5.2.1 Skin Conductance Response Technology

One of the methods of testing physiological change in participants according to color group being shown was measuring skin conductance response. Due to budget constraints, a full GSR machine was not used in this study. In place of a GSR system, a Mindfiled eSense skin response (Biosystems, 2024) was used in order to collect skin conductance data from participants. This skin response was efficient as it was small and portable and could connect to older ipads that had a headphone jack. This skin response technology also could be used with disposable electrodes which was great for hygienic purposes while testing between each participant. This device allowed for easy monitoring of participants' change in skin conductance with output of Microsiemens (μS) and a visual chart.

The way the eSense skin response functions is by connecting to a smart device such as an Android, Iphone, or tablet via headphone jack. Given newer devices do not come equipped with a headphone jack I used an Ipad Air 2 in order to use the device. Once connected to the ipad the eSense device would be synced to the Mindfield app. This app allowed for feedback to be received from the electrodes. This was an efficient and affordable way

to measure skin conductance response and the output received from the device was proficient.

5.3 Heart Rate Technology

5.3.1 Heart Rate Technology

In order to measure the heart rates, beats per minute, of participants a wearable monitor was used. This device was the OxyU bluetooth monitor (Vibeat, 2024) and was wearable via wrist. This device also came equipped with a blood oxygen sensor although this data output was not monitored during this study. This device allowed for bluetooth connection to any device. In order to use the monitor it connected to a smart device via bluetooth and synced to the Vibeat app. Through this app,heart rate monitoring was effortless as the application showed the heart rate changes in real time and also displayed a visual chart while in use. The reason for electing to use this specific device is because of its bluetooth capabilities and the feature to monitor data changes via an application.

5.4 Overview

5.4.1 How The Colors Were selected

The colors that were chosen were carefully selected from the Munsell Color Wheel. This wheel was used as it includes primary, secondary, and tertiary colors. This wheel also works with RGB colors which is consistent with

the display format of the Oculus Quest 2. Electing to use this color wheel as a basis for the color group formations of this study allowed me to choose a range of colors. Specifically, the colors that were used for warm colors are red (HEX #f60b0e), red-orange (HEX #ee1a25), orange (HEX #f04524), yellow-orange (HEX #ffb900), and yellow (HEX #fff100). For cool colors, the colors that were selected were violet (HEX #432885), blue-violet (HEX #091b5d), blue (HEX #0051a2), blue-green (HEX #0d98ba), and green (HEX #04724c). The colors yellow-green and red-violet were purposely omitted from this testing as they can sometimes be crossovers of warm and cool colors which could potentially affect the data output from participants.

5.4.2 How Participants Were Recruited

Twenty (20) participants were recruited for this study from the areas of Maryland, DC, and Virginia in order to have two testing groups that were evenly distributed. The distribution was 10 participants for warm colors and 10 participants viewing cool colors. The two groups of participants were used as a method to compare the data of the different reactions for both color groups. Participants in this research project were between the ages of 18 and 34 and had no history of Colorblindness and/or any history of Epilepsy due to the nature of the research. The gender of the participants was not collected, and this was not used as a method for data analysis.

Participants were recruited through flyers, social media, and email. The flyers were posted around the University of Maryland campus. Emails were

sent to students at the University of Maryland through the Information Studies (INST) department. I also reached out to a variety of professors and asked them to forward my email to students for recruitment. Emails were also sent to contacts, such as friends and family of the primary investigator (myself). Participants were also recruited through social media platforms such as Facebook and Instagram using flyer posts. Flyers and social media posts included a QR code that could be scanned, and participants would be taken to Calendly, which is a calendar booking website, in order to register for a timeslot to participate in the study. The personal accounts of the primary investigator were used in order to post flyers on Instagram and Facebook.

Once participants were recruited, they signed up for their desired time slot through Calendly. Each time slot was 60 minutes long, with various times available for participants at different times of the day. These blocks of time were carefully blocked in order to give enough time to go through each step of the study. These time blocks consisted of explaining the process, consent forms, answering any participant questions, filling out the PANAS scales, testing, and setting up. Participants were unable to participate in testing until they gave written consent. All testing and participation occurred at the University of Maryland College Park Campus. Participants were compensated for their time with a $15 Amazon gift card, cookies, and stickers at the end of the testing session.

5.5 Testing

5.5.1 Testing Overview

The study was conducted with an Oculus Quest 2, which showed different colors for a total of 10 minutes. The color visual application was made using the Unity game engine, Visual Studios C#, and the video editing software Premiere Pro. The setup on the Oculus Quest contained two versions of the color simulation application. One version showcased warm colors, and another showcased cool colors. The colors shown depended on the group assigned to the participant. Participants were assigned to color groups at random in no specific order. Each test was conducted through the

Figure 1.

Warm Color Simulation Example

Note. An image of what the simulation looked liked for warm colors. Own work.

Figure 2.

Cool Color Simulation Example

Note. An image of what the simulation looked liked for cool colors. Own work.

VR headset, and while in the headset, the participants were seated and asked to remain still. The VR headset simulated a virtual room in which the participant was contained in. The VR room had colored walls, ceiling, and floor. The room's virtual space changed according to the color group the participant was assigned to.

5.5.2 Consent Procedure

The consent form was provided to all participants and any questions or concerns were answered prior to the study beginning. Each participant received a paper copy of the consent form for their own records. The consent form was given and explained behind closed doors in a private room. Participants were informed that their names would remain confidential and any data collected would not be directly linked to them by anyone other than the primary investigator. Participants were made aware that they were taking part in a study that consisted of wearing a VR headset (Oculus Quest 2) for 10 minutes alongside noise-canceling headphones (Peltors). Participants were notified of the possible symptoms that could occur while wearing a VR headset. These symptoms include but are not limited to eye discomfort, disorientation, headache, and nausea.

Unfortunately, due to the nature of the research, participants were not able to take a break during the testing. Participants were able to stop the testing at any time and decide not to continue. If participants elected to stop

testing, all devices would be removed immediately. Even if the participants decided to stop testing, they were notified that they still may experience side effects. In order to assist with any side effects, participants were able to sit for the remaining duration of their time block. After the full interaction of 60 minutes had been met, participants were asked to relocate out of the testing area so that testing could still continue with the next participant. It's important to note that according to the Oculus Quest health warnings, symptoms may persist or even worsen even hours after usage of the virtual reality headset (Meta, 2024).

Participants were made aware that this study was focused on measuring physical and psychological behavior. In order to conduct this study accurately, participants' physical data needed to be collected, such as heart rate using a pulse monitor device and skin conductance using a skin response sensor. Participants were also informed that prior to beginning the VR simulation and after the simulation, they would be asked to fill out a PANAS scale to gauge any behavioral or emotional change that occurred during testing. Participants were not allowed to move on to testing until the consent form was signed and agreed upon.

5.5.3 Testing Procedures

During testing each participant had their heart rate taken before, during, and after testing in order to accurately collect any changes in response to the VR experience. Heart rates were taken using a Vibeat Wrist

Pulse device. Participants wore the pulse device on their left wrist. Each participant also had levels of skin conductance monitored before, during, and after testing to measure changes. Skin conductance was taken using a Mindfield eSense Skin Response device. The electrodes for the skin response was worn on users non-dominant hand on the distal phalanx of the Index and Middle finger (Shin & Kim, 2020).

Before monitoring any physiological data, participants were asked to fill out a PANAS scale prior to beginning the testing. The PANAS scale consisted of the following emotions that are part of the two positive and negative emotional dimensions: interested, distressed, excited, upset, strong, guilty, scared, hostile, enthusiastic, proud, irritable, alert, ashamed, inspired, nervous, determined, attentive, jittery, active, and afraid. Each item was measured by participants gauging each emotion on a scale from 1 to 5. The number represents the following: 1 = very slightly or not at all, 2 = a little, 3 = moderately, 4 = quite a bit, and 5 = extremely. This scale was used to collect data on their emotions prior to being in the VR headset and viewing the colors.

Once participants filled out the PANAS form, participants had their initial heart rate and skin conductance measured. After the initial physiological data collection was complete, they would be placed into the VR headset to view the color simulation. If the participant was assigned to Group Cool, they were shown cool colors, which would consist of variations of blue, violet, and green. If the participant was assigned to Group Warm, they were shown warm

colors, which consisted of variations of red, yellow, and orange. The simulation shown was a controlled selection of the previously stated colors for 10 minutes. What the viewer saw was also being displayed on a monitor for data comparison of colors being shown, heart rate being taken, and skin conductance levels.

During testing, participants wore sound-canceling headphones (Peltor Headphones) in order to limit any noise distractions. Participants were asked to focus on what they were seeing while in the VR headset and not to remove the headset unless they would like to end the testing early or colors were not being shown. Participants were asked to sit still and not move excessively, as it could skew the data from the heart rate monitoring and skin conductance response. Participants wore the heart rate monitor and skin response sensor for the duration of testing until testing had ended or they elected to end the test early.

Following the testing within the VR headset, the participant had the Peltor headphones and the Oculus Quest 2 removed. Once the headphones and headset were removed, the participant had their heart rate and skin conductance monitored for 2 minutes. After being monitored for 2 minutes and having the data collected, the participant was asked to sit until the heart rate stabilized anywhere between 60bpm and 100bpm. Once the heart rate was at a stable and safe level, the pulse monitor and skin response sensor were removed from the participant.

Once all the testing devices had been removed, the participants were asked to fill out the PANAS scale once again, which still consisted of the same descriptors and the same scale as before. Once the PANAS scale was filled out, the main portion of the testing was completed.

5.5.4 Conclusion of Testing

Once all testing was completed, the participant was reminded that their participation would remain confidential, and no one besides the primary investigator would be able to link the data to them. After the reminder, the participant was thanked for their participation in testing and given a sticker, cookies, and a $15 Amazon gift card. The protocol, if participants ended testing early and did not complete testing, was that they would not be compensated. No participants dropped out of the study early and all participants who signed the consent form completed the full length of the study and everything that was required for data collection. This study was approved by the University of Maryland's Institutional Review Board (protocol 2088989-1, see Appendix A).

Chapter 6: Findings

6.1 Warm Colors

6.1.1 Heart Rate

Table 2.

Average Heart Rate-Warm Colors

Average Heart Rate (Bpm) - Warm Colors			
Participant ID	**Before**	**During**	**After**
101	63	65	64
103	77	78	80
105	78	88	82
107	81	80	83
109	63	65	59
111	112	108	107
113	70	67	73
115	76	76	73
117	74	75	71
119	82	84	87

Note. This table showcases each participants average heart rate for before, durin, and after the VR simulation of Warm Colors. Data collected December 2023.

Table 3.

Mean Heart Rate for Participants -Warm Colors

Descriptive Statistics

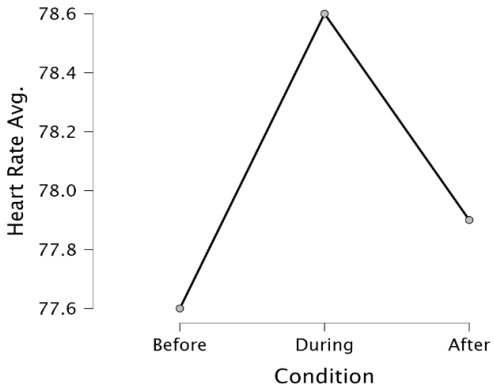
	Heart Rate Avg.		
	Before	During	After
Mean	77.600	78.600	77.900
Std. Deviation	13.802	12.946	13.428

Note. This table showcases each average heart for all 10 participants for the Warm Colors. Data collected December 2023.

For the study, each participant had their heart rate (bpm) taken before, during, and after the VR simulation. Table 2 illustrates the average bpm for each of the 10 participants that were in the warm group. Looking at the average heart rate from before, during, and after, we can calculate the overall percentage change in heart rate. It was found that when comparing all the average heart rates from before the simulation to all the heart rate averages during the simulation (See Table 3.) , there was an average 1.29% increase in heart rate. When looking at the average heart rate of all 10 participants

Figure 3.

Average Heart Rate (Before,During, After) Visual-Warm Colors



Note. This diagram is a visual representation of participants average heart rate for before, during, and after the VR simulation of Warm Colors.

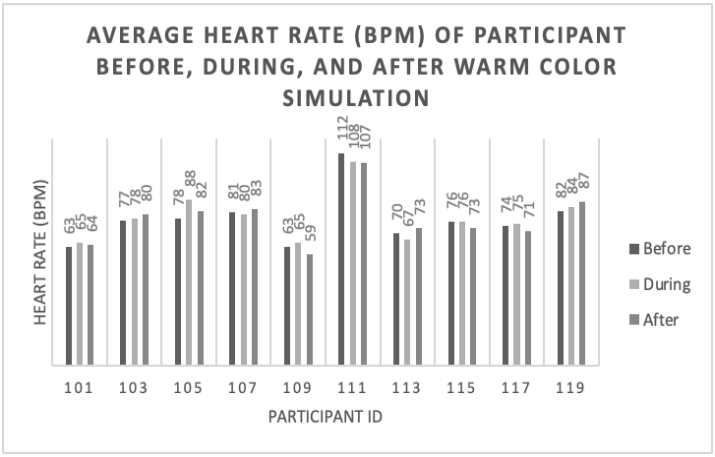
together and comparing before the simulation to after the simulation, there was an overall .89% increase in heart rate. Although there was minimal change in percentage, even this marginal change shows how there was an overall increase when analyzing the data for all 10 participants together.

Among the data that was collected, calculating the mean of all the average heart rates for all 10 participants showcases that the heart rate was 1bpm (77.99bpm round-up 78bpm) higher while viewing the warm color within the VR headset (See Table 3.). Although this is a small increase, it still showcases how, on average, amongst the 10 participants, warm colors increased the heart rate. This data also showcases that even after the color simulation was ended, there were lingering physiological effects for the participants, and their heart rate was an increment 0.3 higher than before the colors were shown.

Analyzing each individual participant, there are multiple points of supporting evidence that showcases the influence of warm colors on participants

Figure 4.

Average Heart Rate Chart - Warm Colors



Note. This chart is a visual representation of participants average heart rate for before, during, and after the VR simulation of Warm Colors.

in the study (Figure 4.). Looking at the averages from before viewing the simulation and comparing them to the average during the simulation, 6 out of 10 participants had an increase in their average bpm. Looking at the average bpm of participants during and after the simulation compared to before the simulation, 8 out of 10 participants experienced an increase in their average bpm. Although participant ID 111 did not have an increase in bpm, they did have an average bpm above 105 the entire duration of testing, even while sitting still within the VR headset. Each of these findings showcase an overall increase in heart rate at some point after beginning the viewing of the warm colors among the participants.

Table 4.

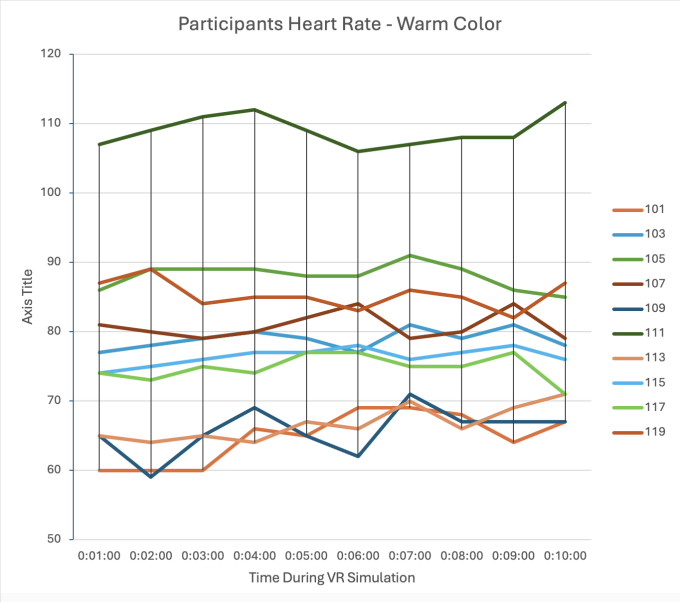
Participant Heart Rate During Simulation - Warm Colors

Warm Colors – Participants Heart Rate per Minute										
	101	103	105	107	109	111	113	115	117	119
0:01:00	60	77	86	81	65	107	65	74	74	87
0:02:00	60	78	89	80	59	109	64	75	73	89
0:03:00	60	79	89	79	65	111	65	76	75	84
0:04:00	66	80	89	80	69	112	64	77	74	85
0:05:00	65	79	88	82	65	109	67	77	77	85
0:06:00	69	77	88	84	62	106	66	78	77	83
0:07:00	69	81	91	79	71	107	70	76	75	86
0:08:00	68	79	89	80	67	108	66	77	75	85
0:09:00	64	81	86	84	67	108	69	78	77	82
0:10:00	67	78	85	79	67	113	71	76	71	87

Note. This table showcases each participants heart rate every minute during the VR simulation of Warm Colors. Data collected December 2023.

Figure 5.

Change in Heart Rate Visualization - Warm Colors



Note. This visualization showcases each participants heart rate every minute during the VR simulation of Warm Colors. Data collected December 2023.

Analyzing the results of the participant's heart rates during the duration of viewing the warm colors within the VR headset (See Table 4.) gave a wide range of interesting results. Looking at the timestamps, significant results of an increase in heart rate were at the 2-minute to the 4-minute mark. At these time stamps, there were more results showcasing the influence of warm colors on increasing heart rate, with 80% of participants having an increase in their bpm. Evaluating all 10 minutes for each participant, 70% of participants who viewed the warm colors had an increase or at least had the same bpm throughout the entire simulation. Overall, 100% of the participants experienced an increase in heart rate at some point in the simulation.

The statistical data among the 10 participants who viewed the warm colors also had some interesting findings that showed a common denominator. Looking at Table 5, there is a common theme among the mean, minimum, and maximum. Among all three aggregated function points and

Table 5.

Statistics for Heart Rate During Simulation - Warm Colors

Descriptive Statistics

	Avg Bpm for Participants for 10 minutes (Warm Color VR)									
	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
Mean	77.600	77.600	78.300	79.600	79.400	79.000	80.500	79.400	79.600	79.400
Std. Deviation	13.697	15.349	14.614	13.930	13.201	12.552	11.683	12.607	12.465	13.664
Minimum	60.000	59.000	60.000	64.000	65.000	62.000	69.000	66.000	64.000	67.000
Maximum	107.000	109.000	111.000	112.000	109.000	106.000	107.000	108.000	108.000	113.000

Note. This table showcases the statical data for heart rate for every minutes during the VR simulation of Warm Colors (calculated with the data from all 10 participants). Data collected December 2023.

comparing the 10th minute to the 1st minute there was a significant increase in the bpm for the data calculated for all 10 participants. Evaluating the mean bpm of each minute for the 10 participants in group warm showcases that for the duration of the entire 10 minutes, the average bpm either remained the same or increased. At the 7-minute mark, the mean was also at its highest at 81 bpm (80.5), which was 3.6% higher than the 1-minute mark mean bpm (78 (77.6)).

Another interesting finding is looking at the minimum and maximum data. For the minimum heart rate, the lowest minimum of bpm was at 2 minutes. During the 2-minute mark, participants were more exposed to a higher percentage of yellow compared to red and orange. The maximum heart rate had very similar results as the bpm was only lower at the 6-minute mark but overall remained higher than the starting bpm of 107. at the 6-minute mark, participants were seeing primarily red with some red-orange but almost no yellow. This is interesting as the highest maximum (113 bpm) was at the 10-minute mark. During this point, the visualization was primarily yellow. This showcases how the concentration of the color being shown may have an effect on heart rate. This statistical data shows that, on average among all 10 participants for group warm, there was an increase in heart rate during the 10 minutes of the VR simulation.

6.1.2 Skin Conductance Data

Table 6.

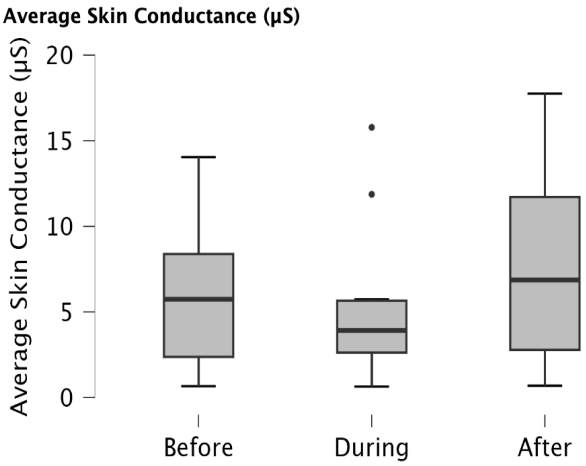
Participant Average SCR - Warm Colors

Average Skin Conductance (µS) - Warm Colors			
Participant ID	**Before**	**During**	**After**
101	0,66	0,64	0,69
103	2,97	3,94	4,42
105	5,25	3,42	4,06
107	6,23	3,89	10,61
109	8,55	5,42	9,31
111	12,52	11,87	12,08
113	2,00	0,88	1,53
115	7,88	5,74	12,5
117	14,04	15,78	17,75
119	2,17	2,36	2,36

Note. This table showcases each participants average skin conductance for before , during, and after the VR simulation of Warm Colors. Data collected December 2023.

Figure 6.

Changes in SCR Visualization - Warm Colors



Note. This visualization showcases overall participants changes of skin conductance for before, during, and after the VR simulation of Warm Colors. Data collected December 2023.

Examining the average skin response data for each participant, the results were staggering. Despite the findings from previous research, the results from this simulation were quite different for physiological responses. Looking at Table 6. the data showcased during the simulation, 80% of participants assigned to the warm color group experienced an average decrease in skin conductance rate (SCR) compared to their starting SCR. This is surprising as over half of the participants experienced an increase in bpm during the showcasing of warm colors, illustrating there was an arousal

effect despite the SCR of majority of the participants decreasing during the showing of warm colors.

Although the average SCR for participants decreased during the VR showing of warm colors, it was found that 60% of participants had an increase in SCR immediately after the simulation ended. This may showcase a delayed reaction time from the warm colors that were being shown. Overall, looking at the average SCR for participants, findings show that 70% of participants had an increase of skin conductance either during or immediately after the simulation when comparing it to their average SCR that was taken before the warm color simulation was shown.

Examining all the data, the mean, minimum, and maximum of all 10 participants together not only showcases the findings stated previously but also reveals some new insights (Table 7.). Looking at the mean, we can see that even when looking at all 10 participants together, the mean result among participants was that SCR decreased during the simulation but had an increase immediately after. This is also the same for minimum skin conductance that occurred between all 10 participants. The minimum SCR between all 10 participants reached its lowest rate during the simulation compared to before and after. Surprisingly, even though the minimum and mean were lowest during the

Table 7.

Statistics for SCR - Warm Colors

Descriptive Statistics ▼

	Average Skin Conductance (μS)		
	Before	During	After
Mean	6.227	5.394	7.531
Minimum	0.660	0.640	0.690
Maximum	14.040	15.780	17.750

Note. This table showcases the statical data for SCR during the testing of Warm Colors (calculated with the data from all 10 participants). Data collected December 2023.

simulations, the SCR had a higher maximum reaching point than before. The maximum peaks gradually increased from during to after, showcasing that although there were lower minimums and overall lower averages, there were higher peaks of SCR once the simulation started and was shown.

Table 8.

Participant's SCR for 10 Minutes - Warm Colors

Participant's SCR During the 10 Minute Simulation - Warm Colors										
Participant ID	**0:01:00**	**0:02:00**	**0:03:00**	**0:04:00**	**0:05:00**	**0:06:00**	**0:07:00**	**0:08:00**	**0:09:00**	**0:10:00**
101	0.71	0.7	0.67	0.66	0.64	0.64	0.64	0.64	0.63	0.64
103	3.89	3.98	4	4	3.96	3.93	3.95	3.89	3.81	3.93
105	4.86	4.2	3.87	3.52	3.31	3.1	2.94	2.88	2.88	2.82
107	8.04	7.5	7.17	6.48	5.88	5.27	4.67	4.17	3.78	3.48
109	9.96	9.5	8.22	6.83	7.04	6.26	5.04	4.87	4.59	4.63
111	12.7	11.04	10.46	10.4	11.07	12.34	11.82	11.94	12.38	11.34
113	0.91	0.82	0.78	0.99	0.88	0.85	0.83	0.84	0.87	0.92
115	7.89	7.3	5.1	5.85	7.04	5.94	3.9	3.26	4.05	4.64
117	20.97	18.7	13.98	13.14	13.99	14.17	12.62	11.95	14.73	23.29
119	2.29	2.34	2.35	2.37	2.4	2.4	2.35	2.35	2.39	2.4

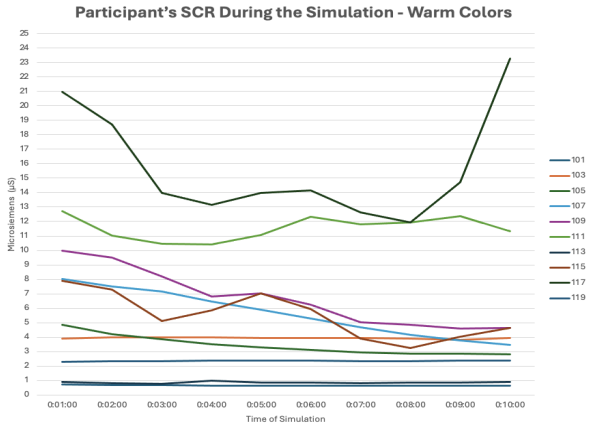
Note. This table showcases the data for SCR during the duration (10 minutes) of the simulation for Warm Colors. Data collected December 2023.

Looking at the breakdown of the SCR for each participant over the 10 minutes of the simulation, we can see that the majority of the participants experienced a decrease in SCR. 60% of participants experienced a decrease in SCR by the 10-minute mark when compared to the 1-minute mark of the simulation. This data does showcase that although the majority of the participants experienced an overall decrease in SCR, one participant, ID 117, experienced a rapid increase in SCR from the 9-minute mark to the 10-minute mark. This is interesting because, looking back at the changes in heart rate at

the 10-minute mark, the highest maximum bpm was also experienced. This showcases the colors being shown at 10 minutes, which were mostly yellow, may cause arousal for some participants. Although there were some interesting outliers of increase in SCR among participants for warm colors, overall, participants experienced a decrease in SCR for the duration of the 10-minute warm color simulation. This showcases that although there was evidence of stimulation in the heart rate data, this medium did not create the same effect for SCR data.

Figure 7.

SCR Changes Visualization - Warm Colors



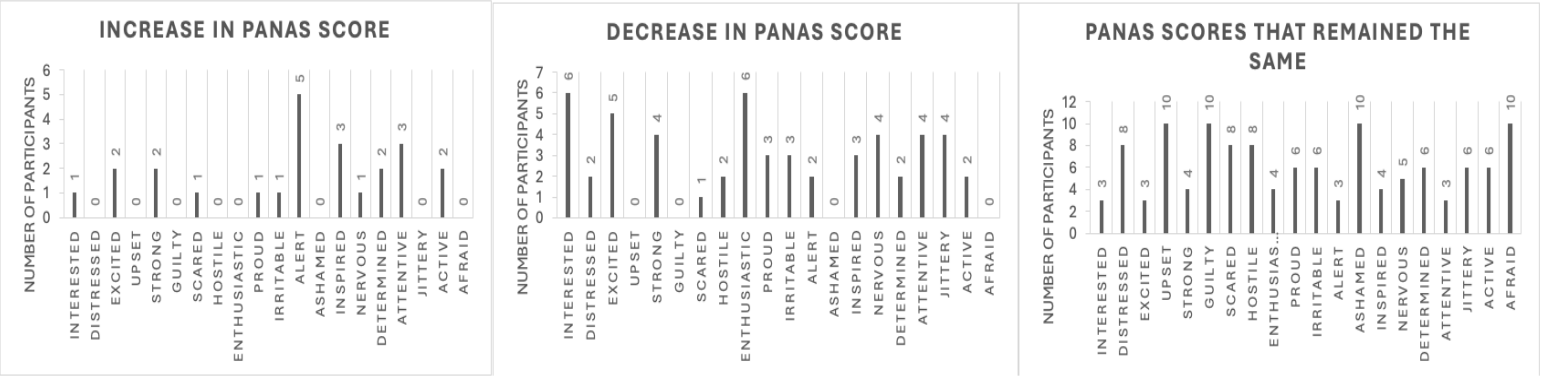
Note. This chart is a visual representation of participants SCR changes during the showcasing of warm colors in the VR headset..

6.1.3 Warm Color - PANAS

The PANAS scale was an important tool as it allowed for a more in-depth overview to see how participants' emotions were affected due to being assigned to the color group warm. More specifically, it allowed further assessment of the changes in scores that participants gave for emotions from before viewing the colors to after. As a reminder, the PANAS has 20 emotions and has a rating scale from 1 to 5. The numbers represent the following: 1 = very slightly or not at all, 2 = a little, 3 = moderately, 4 = quite a bit, and 5 = extremely.

Figure 8.

PANAS Changes Visualization - Warm Colors



Note. This is a visual representation of participants changes in PANAS scores from before to after the showcasing of warm colors in the VR headset..

Analyzing the PANAS scores, it is important to take into account that the starting scores that participants gave on the scale for each emotion will vary, as this was taken before any testing was conducted. Therefore, the ratings were influenced by outside factors that were unable to be controlled in the scope of this study. Instead I will be discussing the changes and patterns that were seen while comparing the before and after ratings of the PANAS scale for all 10 participants assigned to group warm. The first observation is that the emotion ‘Alert’ had the most significant change in PANAS score, with 50% of participants showcasing they felt more alert after the showing of warm

colors. It was also found that 30% of participants felt more ‘attentive’ and ‘inspired’.

Another compelling finding looking at the changes in PANAS scores is that many of the emotions actually decreased in scores by the participants after the simulation. 60% of participants said they felt less ‘enthusiastic’ after the colors were shown. This is interesting as some of these participants still rated the warm colors as making them feel ‘moderately’, ‘quite a bit’, or even ‘extremely’ excited. This is intriguing because enthusiasm is often used interchangeably or cohesively with excitement (Group, 2013). Also, it's important to note that enthusiasm and excitement are also known to have the same positive affect, so the circumstance of these two emotions being rated differently is a compelling observation. These changes and findings in the PANAS scores allowed us to observe the effect warm colors have on participants' emotions and perceptions.

6.2 Cool Colors

6.2.1 Heart Rate Data

Table 9.

Average Heart Rate- Cool Colors

Average Heart Rate (Bpm) - Cool Colors			
Participant	**Before**	**During**	**After**
202	66	60	63
204	56	56	54
206	83	84	79
208	75	72	72
210	109	102	99
212	82	72	72
214	76	73	73
216	93	89	88
218	77	71	71
220	66	64	61

Note. This table showcases each participants average heart rate for before, durin, and after the VR simulation of Cool Colors. Data collected December 2023.

Table 10.

Mean Heart Rate for Participants -Cool Colors

Descriptive Statistics ▼

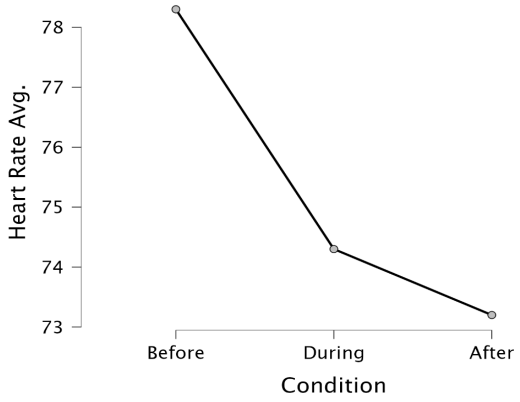
	Heart Rate Avg.		
	Before	During	After
Mean	78.300	74.300	73.200
Std. Deviation	14.952	13.929	13.113

Note. This table showcases each average heart for all 10 participants for the Cool Colors. Data collected December 2023.

The results gathered from the 10 participants who were assigned to Group Cool were overwhelming, as many of the participants had similar results. It's important to remember that the participants in this group were shown variations of the colors blue, green, and violet. These cool colors had a significant impact on the participants, and this was showcased in the data collected. looking at the average bpm of each participant during the simulation of cool colors and comparing it to the average bpm taken before showing the colors through the VR headset, 90% of participants experienced a decrease in heart rate. This decrease in heart rate continued to take effect

Figure 9.

Average Heart Rate (Before,During, After) Visual - Cool Colors



Note. This diagram is a visual representation of participants average heart rate for before, during, and after the VR simulation of Cool Colors.

even after the simulation had stopped, as all 10 of the participants still had a decrease in their average heart rate when comparing the after bpm to the bpm that was collected before the showcasing of cool colors. Overall, looking at the average heart rates of each participant taken during and after the simulation and comparing it to before, all 10 participants experienced a decrease in Bpm either during or after viewing the cool colors (See Table 9.). Looking at the average heart rate for the collective of all 10 participants who viewed the cool colors, we can calculate and observe the percentage change from before to during the simulation (See Table 10.). Overall, the 10 participants experienced a 5.10% decrease when looking at the bpm average during the VR experience among all participants compared to the bpm average before the simulation. When looking at the decrease from before to after, there was a 6.97% decrease in heart rate. Lastly, when looking at the change in average heart rate from during the simulation of cool colors to after the viewing, there was a 1.5% decrease. Looking at the data, it is clear that there was a clear calming effect on participants as, on average, the participants continued to have a decrease in heart rate once viewing the cool colors.

Table 11.

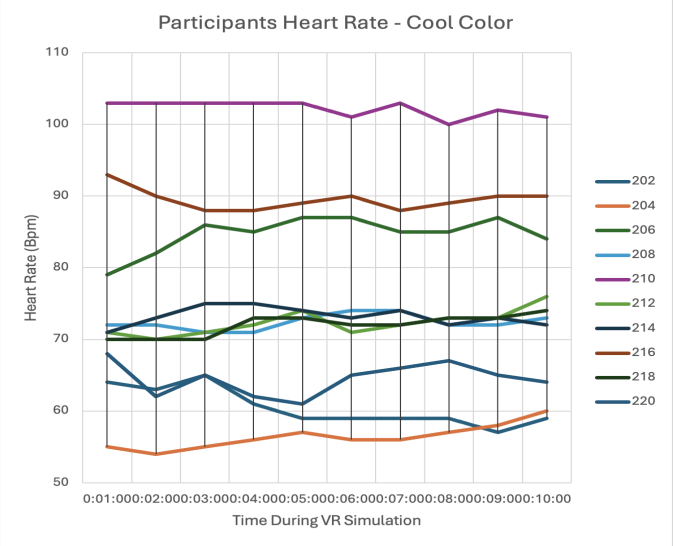
Participant Heart Rate During Simulation - Cool Colors

Cool Colors – Participants Heart Rate per Minute										
Time	**202**	**204**	**206**	**208**	**210**	**212**	**214**	**216**	**218**	**220**
0:01:00	64	55	79	72	103	71	71	93	70	68
0:02:00	63	54	82	72	103	70	73	90	70	62
0:03:00	65	55	86	71	103	71	75	88	70	65
0:04:00	61	56	85	71	103	72	75	88	73	62
0:05:00	59	57	87	73	103	74	74	89	73	61
0:06:00	59	56	87	74	101	71	73	90	72	65
0:07:00	59	56	85	74	103	72	74	88	72	66
0:08:00	59	57	85	72	100	73	72	89	73	67
0:09:00	57	58	87	72	102	73	73	90	73	65
0:10:00	59	60	84	73	101	76	72	90	74	64

Note. This table showcases each participants heart rate every minute during the VR simulation of Cool Colors. Data collected December 2023.

Figure 10.

Change in Heart Rate Visualization - Cool Colors



Note. This visualization showcases each participants heart rate every minute during the VR simulation of Cool Colors. Data collected December 2023.

Taking a further look at the heart rates of each participant during the showcasing of cool colors within the VR headset, we can see closely the changes in heart rate for every minute that was experienced in the simulation. The first observation is that by the 2-minute mark, 80% of participants had already experienced a decrease in bpm. Another observation is that 60% of participants experienced relatively low heart rates that remained under 75 bpm for the duration of the cool colors being shown. Although not every participant remained under 75 bpm, and some even had heart rates above 90 bpm, it's important to note that participants' heart rates remained within 10

bpm of their starting heart rate if they did increase. Lastly, although there would be a slight increase in heart rates at specific points on the testing for some participants, it is important to note that by the 10-minute mark, the participants would either have a lower bpm or no more than a 5bpm increase of heart when comparing it to the 1-minute mark.

Table 12.

Statistics for Heart Rate During Simulation - Cool Colors

Descriptive Statistics

	Avg Bpm for Participants for 10 minutes (Cool Color VR)									
	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
Mean	74.600	73.900	74.900	74.600	75.000	74.800	74.900	74.700	75.000	75.300
Std. Deviation	13.978	14.387	13.868	14.167	14.568	14.109	14.027	13.292	14.267	13.325
Minimum	55.000	54.000	55.000	56.000	57.000	56.000	56.000	57.000	57.000	59.000
Maximum	103.000	103.000	103.000	103.000	103.000	101.000	103.000	100.000	102.000	101.000

Cool Colors (calculated with the data from all 10 participants). Data collected December 2023.

Analyzing the descriptive statistical data for the average bpm among all 10 participants for each minute of the simulation allows for some interesting yet expected, findings. The first data point in Table 12, is the combined mean calculation using all 10 participants' individual outcomes in bpm. Looking at the mean for each minute, we are able to see that, on average, participants experienced the lowest heart rate at the 2-minute mark, as the mean at this time was 74 bpm (73.9). This aligns with previous data discussed in Table 12, as 80% of participants experienced a decrease in heart rate at this same point in the simulation. During this point in the VR

simulation, the only colors shown were blue variations. This shows that blue may be impactful when creating a calming effect among participants and may affect physiological data in a way that would decrease heart rate.

Another interesting data point is the minimum and maximum results of all 10 participants. When analyzing these two descriptives, it's important to remember that these two aggregate functions are not the minimum and maximum of one participant but instead among all 10 participants that were in testing. One interesting finding is that the minimum among all participants for each minute was below 60 bpm. This means that for the entire duration of the cool colors being shown, the minimum heart rate was always lower than the normal resting heart rate, which for adults is between 60 bpm and 100 bpm (Direct, 2022). Lastly, I want to point out that the maximum among all participants also decreased over the duration of 10 minutes. During the first minute, the maximum heart rate was 103 bpm, which remained at the maximum until a little over the halfway point in the VR simulation. By the 10-minute mark, the maximum heart rate had decreased gradually and had the final reading of 101 bpm. This showcases how the maximum heart rate never exceeded the starting maximum but only remained the same and decreased, showing clear effects of cool colors on participants' heart rates, keeping them steady and even lowering them.

6.2.2 Skin Conductance

Table 13.

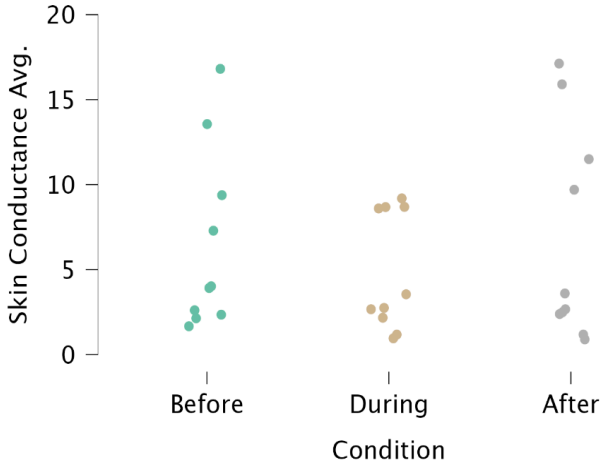
Participant Average SCR - Cool Colors

Average Skin Conductance (µS) - Cool Colors			
Participant	**Before**	**During**	**After**
202	2,14	1,18	1,18
204	2,35	2,17	2,49
206	2,61	2,75	2,39
208	1,67	0,96	0,90
210	13,56	8,68	17,12
212	9,38	8,60	9,70
214	3,92	3,55	3,6
216	4,02	2,67	2,67
218	16,81	9,19	15,9
220	7,29	8,69	11,5

Note. This table showcases each participants average skin conductance for before , during, and after the VR simulation of Cool Colors. Data collected December 2023.

Figure11.

Changes in SCR Visualization - Cool Colors



Note. This visualization showcases overall participants changes of skin conductance for before, during, and after the VR simulation of Cool Colors. Data collected December 2023.

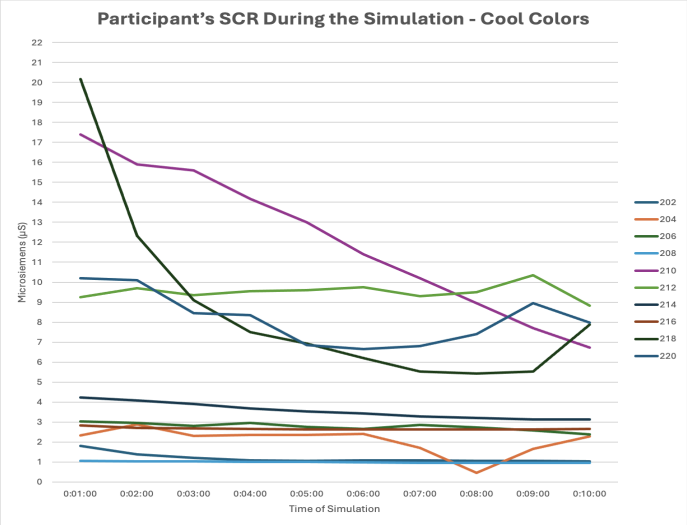
The findings for the average skin conductance among the participants for group cool for before, during, and after were quite interesting but nonetheless somewhat expected and consistent with the findings of the heart rate data. Looking at Table 13, the first finding is that 90% of the participants who viewed the cool colors experienced decreased SCR during the VR simulation. Remarkably, this finding was inconsistent with the data that occurred immediately after the simulation, where only 70% of participants experienced a decrease in skin response. Although there were some spikes in SCR immediately after the showing of the cool colors, it's important to note

that all 10 participants experienced a decrease in skin conductance, whether during or after the simulation.

Observing the overall aggregated functions of mean, minimum, and maximum for all 10 participants together in Table 14 solidifies the findings above that showcased more participants experienced a decrease in skin response during the simulation rather than immediately after the cool color viewing. Among all aggregated functions, it is clear that during the viewing of the cool colors, the skin conductance response is significantly lower than the starting skin conductance response. This shows that although the cool colors had an immediate effect on skin response during the simulation, these effects did not last on the participant after the simulation ended.

Figure 12.

SCR Changes Visualization - Cool Colors



Note. This chart is a visual representation of participants SCR changes during the showcasing of Cool colors in the VR headset.

Table 14.

Statistics for SCR - Cool Colors

Descriptive Statistics

	Skin Conductance Avg.		
	Before	During	After
Mean	6.375	4.844	6.745
Minimum	1.670	0.960	0.900
Maximum	16.810	9.190	17.120

Note. This table showcases the statical data for SCR during the testing of Cool Colors (calculated with the data from all 10 participants). Data collected December 2023.

The last observation for SCR for participants viewing the cool colors are the results collected for each minute of the VR simulation (See Table 15.). The first observation is that when looking at the beginning of the simulation at the 1-minute mark compared to the end at the 10-minute mark, all 10 participants experienced a decrease in SCR. This is also visualized in Figure 12, where it can be seen that by the end of the simulation, each participant has a lower SCR than when they started. The only significant peak during the cool color simulation was was at the 9-minute mark, where 50% of participants experienced a sudden increase in SCR. During this time, participants viewed a higher concentration of green, showcasing that green may have a higher arousal response than other cool colors, such as blue. Seeing the change of SCR for each participant for the duration of the simulation enables us to see how impactful cool colors can be on physiological data.

Table 15.

Participant's SCR for 10 Minutes - Cool Colors

Participant's SCR During the 10 Minute Simulation - Cool Colors										
Participant ID	0:01:00	0:02:00	0:03:00	0:04:00	0:05:00	0:06:00	0:07:00	0:08:00	0:09:00	0:10:00
202	1.8	1.38	1.2	1.09	1.06	1.08	1.08	1.07	1.05	1.04
204	2.33	2.87	2.32	2.36	2.36	2.42	1.7	0.46	1.67	2.28
206	3.02	2.96	2.8	2.95	2.76	2.65	2.86	2.74	2.57	2.38
208	1.05	1.04	1.03	1.01	1	0.99	0.97	0.97	0.97	0.95
210	17.4	15.89	15.6	14.18	13	11.41	10.21	8.94	7.7	6.73
212	9.25	9.71	9.36	9.54	9.6	9.76	9.31	9.49	10.35	8.82
214	4.22	4.08	3.91	3.69	3.52	3.42	3.29	3.2	3.12	3.13
216	2.84	2.71	2.68	2.65	2.63	2.63	2.62	2.63	2.63	2.66
218	20.16	12.33	9.09	7.5	6.93	6.21	5.52	5.43	5.54	7.88
220	10.2	10.11	8.45	8.35	6.85	6.65	6.8	7.4	8.95	7.99

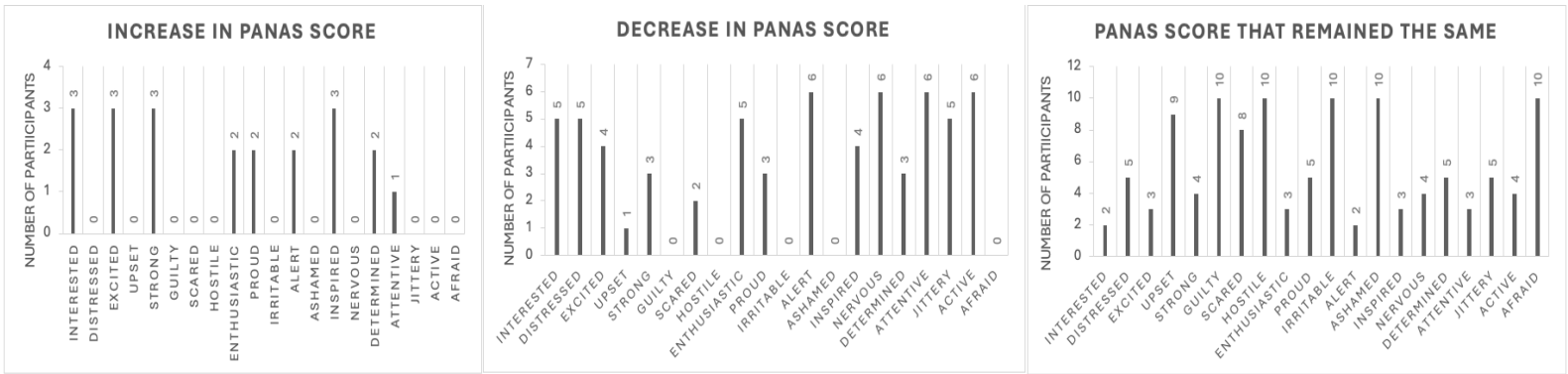
Note. This table showcases the data for SCR during the duration (10 minutes) of the simulation for Cool Colors. Data collected December 2023.

6.2.3 PANAS Scores

The findings from the PANAS scale that was filled out by the 10 participants before and after the viewing of the cool colors were very consistent with the physiological data that was studied and collected. The first important finding was that many of the emotions decreased in rating after the cool colors were viewed by the participants (Figure 13.). More specifically, most of the emotions were rated within “Slightly or not at all” and “A Little” after the VR visualizations. Emotions such as being alert, nervous, and attentive decreased the most among participants after the simulation. The emotion “Interested” had the most participants rate the highest score on the PANAS scale after the simulation was conducted.

Figure 13.

PANAS Changes Visualization - Cool Colors



Note. This is a visual representation of participants changes in PANAS scores from before to after the showcasing of cool colors in the VR headset..

Overall, many of the emotions remained low on the rating scale or decreased in rating after the simulation. It is also important to note that the emotions that did have the most increase in rating were only rated higher by 30% of participants. These emotions were ‘interested’, ‘excited’, ‘strong’, and ‘inspired’, which are all words that would be considered to have positive valance compared to the emotions that decreased in the score, which are consistent with negative valance. The PANAS scale was a great measurement alongside the physiological data collected for cool colors as it allowed for emotions to be clearly connected with physiological changes that occurred due to the cool color simulation.

6.3 The Success of Heart Rate Measuring

6.3.1 Connection between Heart Rate and Emotions

Looking at the warm color group and the heart rate data collected alongside the PANAS data that was observed, there are some clear trends. It was found that, on average, over half of the participants experienced an increase in heart rate during the simulation, and overall, 80% of participants experienced an increase in heart rate either during or immediately after showcasing some lingering effect of the warm colors on physiological behavior. This increase in heart rate is also consistent with the increase in ratings of emotions on the PANAS scale. More specifically, the emotions that increased in rating, such as ‘Alert’ and ‘Attentive’, are also associated with higher arousal. This is consistent with previous studies discussed in this

paper, which showcase that events that cause stimulation and arousal also affect physiological data, such as increasing heart rate (Johnston & Anastasiades, 1990). This also shows how warm colors were not only associated with having higher ratings for emotions connected with arousal but that the physiological data of heart rate also supports the emotions that participants associated with higher scores on the PANAS scale.

Much like the warm colors that were being seen, cool colors were also found to have consistent data and cohesiveness when comparing heart rate with the data collected from the PANAS scale among participants. The findings of heart rate data among the participants who viewed the cool colors showcased an average decrease in heart rate. This is consistent with the decrease in scores for emotions high on the arousal scale. As stated previously, 90% of participants experienced a decrease in their average bpm during the simulation, and all 10 participants experienced a decrease in heart rate either during or immediately after the simulation. This finding is consistent because it showcases that cool colors did not cause arousal in physiological behavior. This was also recognized in the PANAS scales among participants as emotions rated high on arousal decreased in ratings after the participants viewed the cool colors. This shows how cool colors not only had a calming effect on participants but also showcases that participants recognized this through their emotions and could articulate this through the PANAS scale.

6.3.2 How Heart Rate Aligned with Hypothesis

For this study, I hypothesized that warm colors would increase heart rate and cool colors would decrease heart rate. I also hypothesized that due to the physiological effect of the colors, there would be psychological effects that could be seen by participants rating how they felt after viewing the colors through the PANAS scale. This study showed how warm colors had an effect on arousal and stimulation in comparison to cool colors. This study showed how colors can potentially have an affect on a participant's heart rate and that it can change a participant's psychological behavior due to the colors having a stimulating or calming effect on viewers.

6.4 The Nature of Skin Conductance Response (SCR)

6.4.1 Skin Conductance Findings

Previous findings showed that skin conductance response (SCR) is correlated with arousal and stimulation. Studies have also shown that SCR can be measured against heart rate, and if the heart rate increases, then the SCR should also increase (Brouwer & Hogervorst, 2014). This was not the case during this research test. Surprisingly, the opposite occurred among the participants in this testing. It was found that although there was an increase in heart rate for participants during the warm color simulation, there was an overall decrease in SCR when comparing starting μS with the data collected during the VR simulation.

In this study, it was also found that although heart rates decreased for 90% of participants even after the viewing of cool colors, that 30% of participants had an increase in SCR. This showcases that SCR may not affect everyone in the same way and that factors that are out of the scope of this study may also affect SCR results. Although exposure to cool colors did decrease SCR overall among the participants, which is consistent with heart rate data, SCR also decreased during testing of the warm colors. This might imply that heart rate data may not correlate to SCR data in all mediums of color exposure. It also showcases how SCR results may vary depending on the individual and how they personally react to stimulated and non stimulated events. Overall this may imply that arousal may affect heart rate and SCR differently than what has been previously expected when using a different medium of color exposure.

6.5 Results of PANAS Scale

6.5.1 How It Showed Changes

Through this study, using the PANAS scale allowed for the changes in emotions to be gauged through a rating system. The PANAS scale allowed for a visual to be created on how participants felt before viewing the colors compared to after viewing the colors. This was a useful method as it allowed for changes that occurred psychologically to be quantified through the emotions rated by each participant. This method also allowed for specific emotions to be correlated to each color group. Through this method, it was

showcased that warm colors were associated with emotions that are rated higher on the arousal scale. As for cool colors, it was found that participants rated emotions with high arousal lower on the PANAS scale. Overall, the PANAS scale allowed for a direct correlation to be made of not only the color group association with emotions, but also how psychological and physiological data are connected.

6.6 Overall Results

6.6.1 What Was Learned From The Participant Pool

Through the participant pool of 20 people, 10 for the warm group and 10 for the cool group, observations of changes within each group were able to be analyzed. The data from the participant pool showed any contrasting results between the two color groups. Although some of the findings had small changes due to the small participant pool, there are still conclusions that can be made. The first conclusion is that cool colors have less of a stimulating effect compared to warm colors. In the study, it was found that cool colors decreased the output of the physiological data. Cool colors also had a decrease in scores for emotions that were associated with low valance and high arousal. These results are in contrast with the warm colors, where it was found that, on average, the heart rates of participants in the warm color group would increase. It was also found that warm colors were associated with emotions that are considered high in arousal, such as being ‘alert’.

In conclusion, through the participants and research conducted, it was found that cool colors decrease heart rate and are less likely to be associated with emotions with high arousal and negative connotations. Warm colors were found to increase heart rate and be associated with emotions connected to high arousal. Both color groups were found to have a decrease in SCR, showcasing that this method may not be as efficient and that more research needs to be done on the method to understand its validity and have more conclusive results.

Chapter 7: Discussion

7.1 Limitations and Notes

7.1.1 Future Participant Groups

Although there were interesting findings among the participants between both groups, I believe in order to have a substantial amount of evidence that colors affect participants, there needs to be a larger pool of participants so the analysis of the statistical findings can be found and that the p-value can be obtained. According to the Nielsen Norman Group, 40 participants is ideal for quantitative data (Naz et al., 2017). Although emotions are qualitative because we are analyzing the changes and how many participants showed significant change, 40 would be ideal as it would allow for both the warm group and the cool group to have 20 participants. This would allow for a larger data pool and, therefore, would allow us to see more drastic changes and anomalies among the participants. Overall, having a larger group for testing would allow for more validity among the results and allow for the data patterns to be seen more clearly.

For future participant groups its also important to take in account the demographic of each participant. In order to have a better understanding of the effect of color groups of participants its important to recruit participant of diverse backgrounds, cultures, and gender. I believe these factors can play a role in the opinions and biases on how colors are perceived. For example growing up in the 21st century in the United States I was always taught pink

was always perceived as more fair and dainty while blue was perceived as strong. Having this bias may effect how one may perceive a color group. Another example is culture differences in certain countries. For example in India red is viewed as purity and used for wedding dresses, unlike in western culture where white is viewed as purity and used for weddings (Eriksen, 2023). These difference may affect ones reaction towards colors and therefore it would make for an interesting study to analyze the psychological and physiological changes against the personal background of participants to note and analyze how personal bias affects reactions towards colors.

7.2 Final Thoughts

7.2.1 Future Recommendations

If this research is to be conducted again, one recommendation is to conduct this study with a larger participant pool so that the data could showcase larger percentage changes and and statical significance for both color groups. It is also recommended that other factors be taken into account, such as gender and even cultural background. Another change for future studies is to not use the SCR method as there are too many unknowns, and this study conducted has shown that results will vary. If SCR is elected to be used in future studies, more research is needed on how different mediums, such as VR, affect SCR results. Its also important to look further into the history of SCR and how it may be affected by different outside factors such as room temperature, amount of sleep, and even other senses such as sound.

Going further in research for SCR will allow for a better understanding of the effects on the skin conductance produced by participants and allow for a conclusion to be made on whether or not this is truely a reliable and effective tool of measurement for physiological changes.

The last recommendation for change in this study is to add an interview method to the testing. An interview portion will allow for more in depth questions to be asked to the participants unlike the PANAS which was very contained and only allowed for a set amount of emotions to be identified. Example questions that could be used for an interview could ask about things such as, whats your favorite and least favorite color? What emotions are you feeling currently? What colors did you find intense if any and why? and many other questions of this nature. Questions such as these would allow to have a better understanding of how the colors effected the user and what outside factors may have contributed to these effects. I also believe a personal background survey and/or interview on demographic would also be useful for future studies. Having a survey that ask personal opinions on how one perceives certain colors in their culture or how the participant grew up and how they were taught to view certain colors would also be useful. This would allow to see how personal backgrounds may potentially affect results. Overall being able to go in depth with participants with interviews/surverys would allow for further information to be gathered about the participant's thoughts about the color groups and have more in-depth results on the participants' emotions according to the color group that was viewed.

7.2.2 How Findings Can Be Used

These findings can be used in further research and in various domains. The purpose of these findings is to act as a building block in art, technology, and psychology. Because this research can be applied to various domains, it also falls perfectly under Human-Computer Interaction (HCI). Because HCI heavily focuses on the interaction between technology and humans, this work can be applied to focus on user experience in applications. Knowing how colors affect users can be applied to HCI, as this knowledge allows us to build designs that will create the desired emotional reaction based on the color palette applied. HCI practitioners can also use the findings from this study as a basis to build more ethical designs and conduct further research on UX practices. Ethical designs can be created with these findings as knowing how colors may negatively impact a user allows for designers and HCI practitioners to limit or avoid these colors in there built applications. This also allows researchers in HCI to think further about there own studies when user testing a application and/or prototype that is heavy in colors, because with this knowledge they can take in account how colors may affect the outcome and usecase results of there testing. Since this research was also conducted with VR, it can be applied back to the domain of immersive technology. Understanding how colors affect us is important, especially when immersing users in a virtual environment. Knowing the effect of colors allows us to build impactful scenes (i.e., a blue and green zen garden for a calming effect). Lastly, this research can be a foundation for an application that can be

applied to psychology. Knowing how colors affect users will allow designers to build long-lasting applications, especially when it comes to impacting a user's emotional and physical reaction.

7.2.3 Conclusion

I hope to continue to further this research in the future with the recommendations above and also other sensory elements such as noise, touch, and smell. I would also like to use this study as a basis of understanding colors and how they may effect users in visual applications. My overall goal for this study and future studies is to understand how different colors and other sensory stimuli affect a use. With this knowledge I want create an application and device that will help those that experience anxiety alleviate symptoms they may experience.

Appendices

Appendix A: Institution Review Board Approval Letter

UNIVERSITY OF MARYLAND
INSTITUTIONAL REVIEW BOARD

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DATE:	November 28, 2023
TO:	Ciara Fabian, HCIM
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[2088989-1] Studying the Effects of Colors Within Virtual Reality (VR) on Psychological and Physical Behavior
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	November 28, 2023
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # 4 & 7.

Appendix B: Consent Form

CONSENT TO PARTICIPATE

Project Title	Studying the Effects of Color Within Virtual Reality (VR) on Psychological and Physical Behavior
Purpose of the Study	*This research is being conducted by **Ciara Fabian** at the University of Maryland, College Park. We are inviting you to participate in this research project because you fit the initial age requirement between the ages of 18 and 34 and have no known history of Colorblindness and/or epilepsy. The purpose of this research project is to look at how specific colors shown in Virtual Reality affect a person's emotions, physical reactions, and thinking by measuring heart rate, skin conductance, and using the psychology scale of PANAS.*
Procedures	*This study will take a total of 60 minutes (1-hour). The procedure involves wearing a Virtual Reality headset (Oculus Quest 2) for 10 minutes while viewing a variety of colors and patterns. Answering sensitive questions related to emotional well-being using a Positive and Negative Affect Schedule (PANAS) scale. Wearing a fingertip pulse monitoring system and a skin conductance sensor to measure physical changes. You will have your heart rate taken before, during, and after testing in order to accurately collect any changes in pulse in response to the VR experience. You will wear the pulse device on your left wrist. You will also have your levels of skin conductance taken before, during, and after testing to measure changes. During testing, you will wear sound-canceling headphones (Peltor Headphones) in order to limit any noise distractions. You will be asked to focus on what you are seeing while in the VR headset and not to remove the headset unless you would like to end the testing early or no more colors are being shown. You will be asked to wear the fingertip pulse monitor and skin conductance sensor for the duration of testing until testing has ended or you choose to end the test early. You will be asked to sit and not move excessively. Following the testing within the VR headset, you will be asked to remove the Peltor headphones and the Oculus Quest 2. Once you have removed the headphones and headset, you will be asked to fill out a PANAS scale once again. Once you have finished filling out the scale, you will be asked to sit for 3 minutes to help stabilize your heart rate. Once all testing has been completed, all devices will be removed, and you will be reminded that your participation will remain confidential.*
Potential Risks and Discomforts	*There may be some risks from participating in this research study. Risks include but are not limited to eye discomfort, disorientation, headache, nausea, and hand discomfort. In order to mitigate risks, the devices will be fitted to comfort as best as possible. Unfortunately, due to the nature of the research participants will not be able to take a break during the testing. Participants may stop the*

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	testing at any time and decide not to continue. If participants choose to stop testing, all devices will be removed immediately. Even if the participants choose to stop testing, they still may experience side effects. In order to assist with any side effects participants may sit for the remaining duration of testing. It's important to note that according to the Oculus Quest health warnings symptoms may persists or even worsen even hours after usage of the virtual reality headset.
Potential Benefits	*There are no direct benefits from participating in this research. However, possible benefits include understanding how color affects emotions and physical reactions. We hope that, in the future, other people might benefit from this study through an improved understanding of color effects on users.*
Confidentiality	Any potential loss of confidentiality will be minimized by storing all data in a password-protected computer and on a locked and protected file on Google Drive. No real names will be used when collecting the data and if published the data will not be linked to any of the participants. IDs will be used in place of names so that no data can be connected to the participants. The only identifiable information will be the consent forms which will be stored in a separate folder location. The only people who will have access to identifiable information such as consent forms is the primary investigator Ciara Fabian and the thesis committee. Data will be saved for a maximum of 5 years after final publication. Only the primary investigator and thesis committee will have access to this data. *If we write a report or article about this research project, your identity will be protected to the maximum extent possible. Your information may be shared with representatives of the University of Maryland, College Park, or governmental authorities if you or someone else is in danger or if we are required to do so by law.*
Compensation	*You will receive a $15 Amazon gift card for your participation. You will also receive a cookie and/or sticker for your participation. If participants end testing early and do not complete testing, they will not be compensated.* *You will be responsible for any taxes assessed on the compensation.* *If you earn $100 or more as a research participant in this study, you must provide your name, address, and SSN to receive compensation.* *If you do not earn over $100, only your name and address will be collected to receive compensation.*
Participation	*Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not*

	to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify. *If you decide to stop taking part in the study, if you have questions, concerns, or complaints, or if you need to report an injury related to the research, please contact the investigator:* ***Ciara Fabian*** ***8238 Ironclad ct Gaithersburg, MD 20877*** ***Cfabian4@umd.edu*** ***240.246.4052*** ***Professor. Jason Aston*** ***Aston@umd.edu***
Right to Withdraw and Questions	*If you are a student, your grades, standing, or employability at your institution will not be positively or negatively affected by your participation or non-participation in this study.* *If you have questions about your rights as a research participant or wish to report a research-related injury, please contact:* University of Maryland College Park Institutional Review Board Office 1204 Marie Mount Hall College Park, Maryland, 20742 E-mail: irb@umd.edu Telephone: 301-405-0678 *For more information regarding participant rights, please visit:* https://research.umd.edu/research-resources/research-compliance/institutional-review-board-irb/research-participants *This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.*
Statement of Consent	*Your signature indicates that you are at least 18 years of age; you have read this consent form or have had it read to you; your questions have been answered to your satisfaction; and you voluntarily agree to participate in this research study. You will receive a paper copy of this consent form.* *If you agree to participate, please sign your name below.*
Signature and Date	**NAME OF PARTICIPANT** **[Please Print]**

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	SIGNATURE OF PARTICIPANT	
	DATE	

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